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ORIGINAL ARTICLES.

On a curiously-jointed Pre-glacial Rock-surface at Rhiwbina, near Cardiff.

By Professor ARTHUR HUBERT COX, D.Sc., Ph.D., F.G.S., and E. CYRIL OAKES, A.M.Inst.C.E., A.M.Inst.W.E.

(PLATE XII.)

THE rock surface to be described in this paper was discovered under boulder-clay during excavations for a new reservoir for the City of Cardiff Waterworks at Rhiwbina, 5 miles north of Cardiff. The relation of rock to boulder-clay proved so unusual, by reason of a curious jointing in the rock-surface, that it appeared to be worthy of record.

The site of the new reservoir[1] is situated on the crop of the Old Red Sandstone, and near the junction of the Red Marl and Brownstone divisions of the Old Red Sandstone Series (Fig. 1). The excavations have exposed beneath boulder-clay a series of red marls, sandstones, cornstones, and conglomerates, with a general dip northwards into the hillside at angles up to 40°. These beds, which were not exposed at the time of the geological survey of the district, appear to be near the top of the Red Marl group, and their exposure confirms the accuracy of the 6-inch Geological Survey Map (6-inch quarter-sheet Glamorgan xxxvii, S.W.).

The overlying Brownstone group forms a well-marked scarp capped by the Quartz-conglomerate division. At the point nearest to the reservoir the top of the scarp is at about 550 feet above O. D. Further away the scarp rises gradually to its normal height of about 750 feet. The base of the steep slope is about 250 feet above O. D. The reservoir site is on the lower part of this slope between the 300 and 400 feet contours. The scarp normally runs approximately east-north-eastwards, but behind (or north of) the reservoir, a small transverse fold swings the scarp into a direction nearly north to south. Immediately west, or rather north-west of the reservoir, the scarp is breached by a small stream which has excavated a deep valley.

The reservoir site is thus on an outstanding spur of the hills. South of it extends a wide plain, which descends gradually to sea-level six miles further south. The plain marks the outcrop of the

[1] For engineering features see Neil J. Potters, H. W. B. Cotterill, and B. Santo Crimp, "Various Aspects of the Cardiff Waterworks Undertaking": *Water and Water Engineering*, 21st January, 1924.

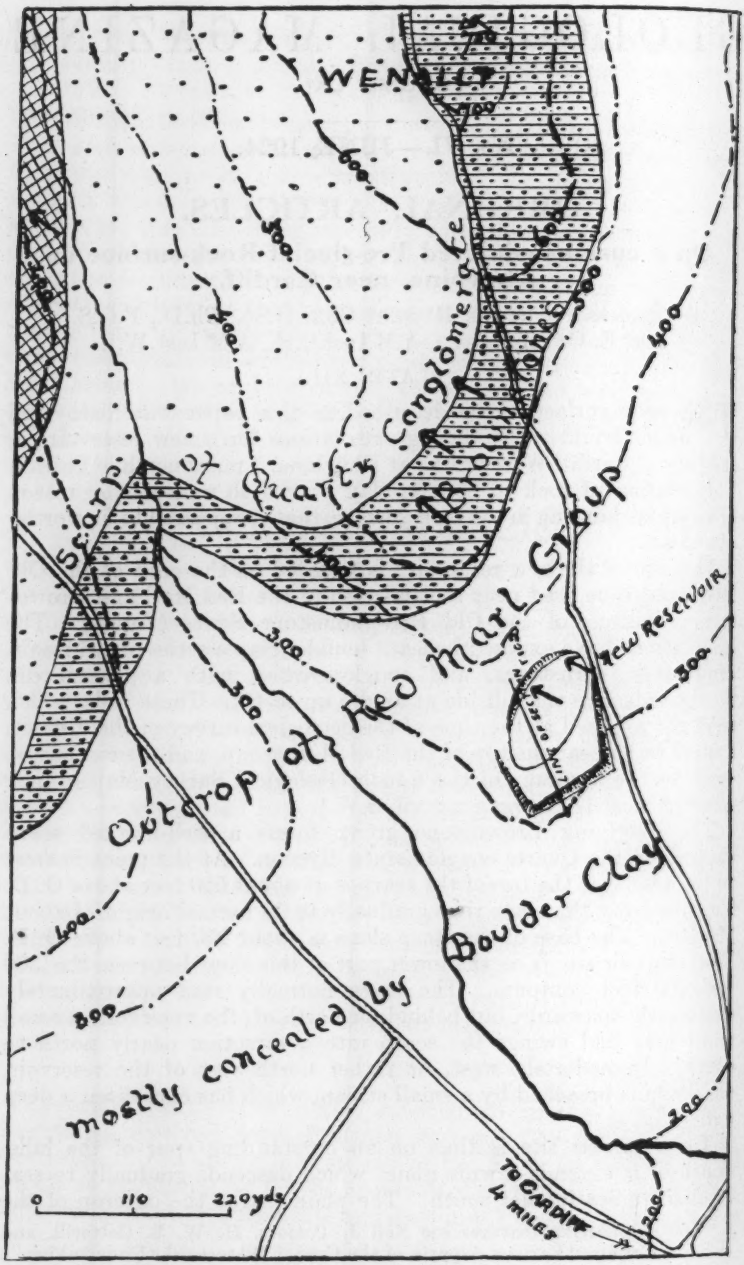


FIG. 1.—Map showing position of new reservoir, Wenallt, Rhiwbina, near Cardiff. (Based on 6 inch Geological Survey Map.)

thick Red Marl division which forms the lower part of the Old Red Sandstone Series. The surface of the plain is almost entirely covered with drift deposits, largely boulder-clay.

The excavations have shown that this boulder-clay mantles the lower slopes of the hill in such a way that it forms a cover averaging about 12 to 15 feet thick, and that the surface of the solid rock is roughly parallel to the present form of the ground (Fig. 2). But the drift cover does not extend to the top of the hills, not in fact much above the level of the new excavations. The slope of the ground was therefore probably somewhat steeper in Pre-glacial times than it is at present. The approximate parallelism between the present slope and the underlying rock-surface is, however, subject to frequent and sudden interruptions, caused by the presence of numerous drift-filled hollows, or channels, which are often very steep-sided. The curiously jointed rock-surface was found at the base of one such hollow; this particular hollow was bounded on the west by a vertical wall of rock about 8 feet in height.

The rock at the base of this hollow, over part of its length, is a conglomerate composed of angular or semi-angular pebbles, normally from 1 to 4 inches in diameter, with occasional large fragments; the pebbles are mostly of a reddish quartzite of variable grain. In other parts of the excavations the pebble-beds have a sandy or marly-sandy matrix, which is almost unconsolidated, and the pebbles may be picked out with the fingers. The beds then recall the Bunter Pebble Beds of the Midlands. But in the particular deep drift-filled hollow where the jointed rock was found, the conglomerate had a strong calcareous cement and formed a very tough rock.

The bedding was horizontal and the rock extended along the hollow for some 45 yards. At both ends it was faulted against horizontally-bedded sandy marls and sandstones with occasional pebbly layers. These sandy beds floored the remainder of the hollow.

The tough conglomerate-rock was split by a network of cracks as shown in the photographs (Pl. XII). The cracks were from a few inches up to 2 or 3 feet in width, and some of them extended to a depth of at least 6 feet. These cracks were infilled with boulder-clay which had to be excavated in order to provide a firm base for the concrete reservoir-wall.

That the cracks originated as joints is indicated in several ways. The conglomerate masses are nearly all in place, as revealed by the bedding; the few exceptions appear to represent tumbled blocks. The cracks display a certain regularity of arrangement comparable with the master-joints in many massive rocks. One set, running nearly north-south, overhang to the east. Along the cracks (or joints) the pebbles stand out from the matrix owing presumably to solvent action on the calcareous matrix. These outstanding pebbles are sharply fractured parallel with the main jointing. The original

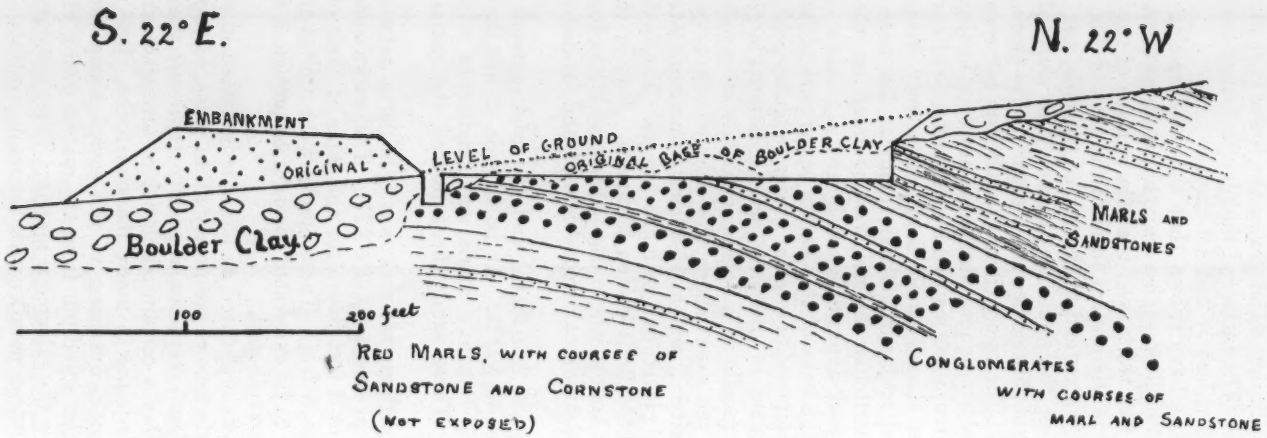


FIG. 2.—Section through new reservoir, Wenallt, Rhiwbina, Glamorganshire, showing position of trench illustrated on Pl. XII.

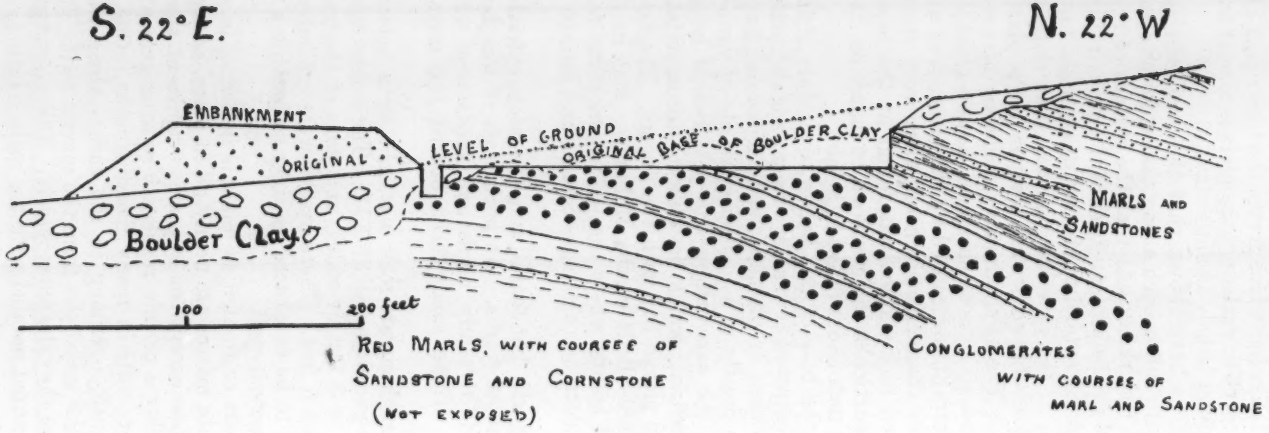
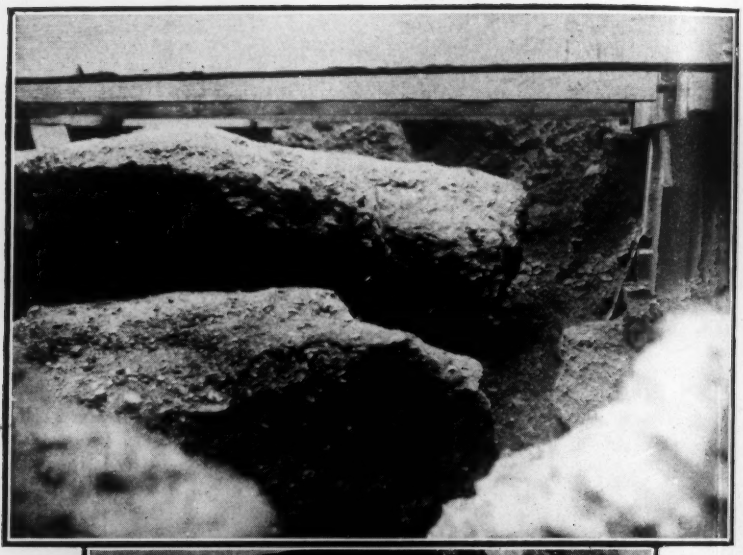


FIG. 2.—Section through new reservoir, Wenallt, Rhiwbina, Glamorganshire, showing position of trench illustrated on Pl. XII.



E. C. Oakes photo.

FIG. 1.—Joints in conglomerate after removal of Boulder-clay, viewed from the side.

FIG. 2.—Jointing in conglomerate beneath Boulder-clay. Rhiwbina, viewed from above.

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width and smoothness of the joints had in some cases been modified by pick and shovel in clearing away infilled boulder-clay. It was noted that water never remained in the hollow, showing that the jointing continued below the level of the excavation.

Another hollow, a few yards away, contained isolated masses of similar rocks separated and overlain by boulder-clay, but in this case none of the blocks were in situ.

The most probable explanation of these occurrences would seem to be that the jointed rock represents a platform adjacent to a buried scarp. It has already been pointed out that the excavations are situate on a projecting spur of the hills, and that the pre-glacial slope of the ground was steeper than the present slope. In the absence of vegetation consequent on the frigid climate, such a massive rock as the calcareous conglomerate would certainly stand out as a bare scarp,[1] and the softer overlying sandstones and marls would be stripped off for some distance away from the edge of the scarp, so that a platform of conglomerate would be exposed, forming a kind of pavement. In such a position any jointing would be further developed by frost action, helped in this case by solution of the calcareous cement. Isolated blocks would fall away from their proper position, leaving overhanging masses of solid rock, and in some cases a whole mass of blocks might tumble into ruin as displayed in the smaller hollow. Similar scarps with a well-jointed pavement are seen in the present day in many sandstone outcrops, e.g. the Bunter Beds in Nottinghamshire and Shropshire, and still better in the Bunter conglomerates of the Vosges.

The question then arises as to why these phenomena are so limited in area and restricted, so far as observed, to one corner of the excavation. Why are they not displayed wherever the conglomerate is covered by boulder-clay ? The probable answer is that in other parts of the excavation the tough calcareous cement is absent and the rock is more friable. Such a friable rock would not allow a clear-cut jointing, and hence would not separate into great rectangular blocks.

The authors desire to express their indebtedness to Mr. C. H. Priestly, M.Inst.C.E., Waterworks Engineer and Manager to the City of Cardiff, for permission to publish this account of an occurrence that presented to the engineers something of a problem when first exposed.

EXPLANATION OF PLATE XII.

FIG. 1.—The conglomerate viewed along the excavation, showing vertical jointing with cleanly-fractured pebbles. The joints have in places been artificially widened during the excavation of the infilling boulder-clay.

FIG. 2.—The surface of the conglomerate bed viewed from above after removal of boulder-clay, showing the pavement-like character of the upper surface, and the master-joints widened by solution. The scale is indicated by the rule.

[1] This has since been proved by a borehole, which started only 3 yards south of the jointed platform, but failed to reach solid rock at a depth of 20 feet.

The Petrography of the Sands of the Upper Lias and Lower Inferior Oolite in the West of England.

By P. G. H. Boswell, University of Liverpool.

I. Introduction.

THE sands which form the highest beds of the Lias and lowest beds of the Inferior Oolite in the area stretching from the Dorset coast to north of Cheltenham have long been of interest on account of their unusual lithological characters and variable stratigraphical horizon (1–17).[1] Certain aspects of their petrography, considered in relation to their distribution and the probable source of their constituents, are dealt with in this paper.

As Mr. S. S. Buckman has demonstrated (5, 17), the sands vary in their stratigraphical horizon. The hemeræ during which they were deposited (as indicated by their ammonite assemblages) have been determined by him as follows :—

		South Dorset. "*Bridport Sands,*" *approx. 150 ft. thick.*	*North Dorset and Somerset.* "*Yeovil Sands,*" *approx. 200 ft. thick.*	*Bruton District.* "*Bruton Sands,*" *approx. 100 ft. thick.*	*Bath District.* "*Midford Sands,*" *approx. 70 ft. thick.*	*Sodbury District.* "*Sodbury Sands,*" *approx. 175 ft. thick.*	*Cotteswold Area.* "*Cotteswold Sands,*" *approx. 250 ft. thick.*
opaliniforme	(o)	—					
venustula	(n)	—					
digna	(m)	—					
Cotteswoldia	(l)	—					
moorei	(k)	—	—				
Catulloceras	(j)	—	—				
Dumortieria	(i)	—	—				
Hammatoceras	(h)			—			
dispansum	(g)			—	—		
struckmanni	(f)				—		
pedicum	(e)						
eseri	(d)						
striatulum	(c)					—	
variabilis	(b)						—
lilli (?) or *semipolitum*[2]	(a)						—

NOTE.—The "Harford Sands" occur above the "Snowshill Clay", and both formations lie between the Upper Freestone and Lower Trigonia-Grit. The sands are of *concave* date (Upper Aalenian), and are, therefore, not considered in this paper, but it may be said that in mineral and mechanical composition they differ notably from the sands here described.

[1] The numbers in parentheses refer to the list of publications at the end of the paper.

[2] Although these sands have been referred to *lilli*, Mr. Buckman informs me that they are probably lower and of *semipolitum* date, *lilli* deposits being absent.

The samples examined, numbering over eighty, have, except as indicated below, been collected by me. Where vertical sections of the deposits permitted it, samples were taken at intervals of 10 to 20 feet. Attention was also paid to the lateral extension of the beds. For additional samples, collected from the various exactly determined horizons at West Bay (Bridport), I have to thank Mr. S. S. Buckman. For samples from the Tetbury and Shipton Moyne boreholes (14, 15) my thanks are due to Mr. Linsdall Richardson.

The chief localities from the neighbourhood of which material has been collected, arranged from north to south, are as follows, the key-letters referring to the hemeræ indicated in the above table :—

Mid Cotteswolds	Gloucester (Robin's Wood Hill)	a.
	Painswick	a.
	Haresfield	a, b.
South Cotteswolds	Frocester	a, b.
	Dursley	a, b.
	Wotton-under-Edge	a.
Sodbury District	Old Sodbury	c.
	Doddington	c.
Bath District	Midford	f.
Mendips	Doulting	g.
	Shepton Mallet	g.
	Bruton	g, h, i.
Cadbury District	Compton Pauncefoot	g, h.
	Holway Hill	i, j, k.
Yeovil District	Bradford Abbas	k, m.
	Yeovil	i, j.
	Stoford	k.
	Ham Hill	k.
	Montacute	i.
Beaminster District	Broadwindsor	k, l, m, n.
	Whaddon Hill	l (?), m, n, o (?).
	Beaminster	j (?), k (?).
	Stoke Abbot	k (?), l, m, n, o (?).
Dorset Coast	Chideock	m, n.
	Bridport	i, j, k, l, m, n, o.

In papers anterior to Mr. Buckman's most recent discussion of these beds (17) the hemeræ *Cotteswoldia*, *digna* and *venustula* appear as *aalensis*.

As terms denoting stratigraphical divisions, the " Bridport Sands ", " Yeovil Sands ", " Midford Sands ",[1] and " Cotteswold Sands " have long been known. The terms " Bruton Sands " and " Sodbury Sands " have recently been introduced by Mr. Buckman.

In addition to the various zones quoted above, a sandy facies is present in the *thorncombeiensis* zone of the Lias (immediately below the *spinatum* zone) and in the pre-*margaritatus* bed. The former is present in South Dorset on Thorncombe Beacon (Mr. Buckman's " Thorncombe Sands ") and the latter is present in the Dorset coast-section and in the Cotteswolds (" Down Cliff Sands "). The petro-

[1] H. B. Woodward used the term " Midford Sands " to include the whole series (6, p. 32).

graphy of samples from these horizons will be dealt with in a future paper on the Lias.

The *venustula-lilli* sands marked a shallow-water phase which set in towards the end of Liassic times and continued, as the wave of shallowing passed southwards, throughout the earlier part of Inferior Oolite times. The sandy phase is characterized by a peculiar, unusual, and easily-recognized lithology and petrology, maintained throughout the area. In consequence, the phenomena provide a striking and diagrammatic example of the crossing of time-planes by planes of lithology.[1]

If these deposits are followed northwards from near Gloucester to Cleeve Hill, near Cheltenham, and then eastwards and north-eastwards through Worcestershire and Oxfordshire, the type of sediment is seen to undergo a marked change. Instead of the uniformly fine sands and silts, alternations of coarser sand and finer clay, interdigitating with one another, occur. The sandy facies passes to a higher zone, that of *scissum*,[2] and in the case of the Harford Sands, to that of *concava*. Differences in mineral composition, suggesting derivation from the north, north-east, or north-west, in contrast to south-westerly drift, are also noted. The discussion of the petrography of the deposits from Gloucestershire to Northamptonshire and Yorkshire provides material for a future paper, the work being now in progress.

In the Cotteswolds northwards and north-eastwards of Birdlip the sandy beds here described become attenuated. Passing southwards from Gloucester, the thickness varies considerably, as shown by the figures given by H. B. Woodward in the Survey Memoir (6) for the sands as a whole, and by Mr. S. S. Buckman, in his various papers, for different hemeræ.

The notable thickness of sands at many localities, considered in the light of the persistence of lithological character from top to bottom, indicates the maintenance of similar conditions such as depth of water, approximate distance from shore-line, etc., which must have resulted from a steady depression of the sea-floor accompanied by down-warping. The passage of the sandy phase across the zones indicates, as already stated, that it arrived in successively later hemeræ as the deposits are traced southwards. The conditions were those of (*a*) a shallowing in the Cotteswold area in late Liassic times, whilst fairly deep water prevailed farther south; (*b*) the passage of an earth-wave southwards, progressively elevating the parts of the intervening area between the Cotteswolds and Dorset, the effect of the shallowing being such as to cut off the supply of terrigenous sediment from the area on the north, where, in the clearer water, limestones began to be formed; (*c*) a shallowing in the Dorset area

[1] Presidential Address, *Trans. Liverpool Biol. Soc.*, vol. xxxv, 1921.

[2] It is noteworthy that, as Mr. Buckman has pointed out, the Cotteswolds were parted from Dorset and Somerset about the time of *scissum*, the connexion not being restored until *garantiana*.

with a general tilt towards the deeper clear-water area on the north ; (*d*) the passage of the ripple into the area of the Channel, and the deposition of limestones over the whole district under consideration.

That the condition of instability persisted for some time after these events is indicated in the succeeding Aalenian and Bajocian deposits by the non-sequences, evidences of contemporaneous erosion, and overlap in the proximity of the rising Mendip ridge.

II. Mechanical Analyses.

Two outstanding features are revealed by mechanical analyses of the sands, (*a*) their extreme fineness of grade, as sands, and (*b*) their maintenance, within certain limits noted below, of this grade over the whole outcrop, despite the change of horizon undergone by them.

The sands are characterized by the high proportion of what is commonly termed " silt-grade " (0·1 to 0·01 mm. diameter). Subdivision of this grade into the coarser portion (0·1 to 0·05 mm. diameter = coarse silt or very fine sand) and finer portion (0·05 to 0·01 mm. diameter = fine silt or " silt " of some writers) shows that the former always largely predominates. Moreover, as is well-known, the deposits behave in the field as sands proper, that is, they form an important water-bearing horizon and their outcrop carries a typical " sandy " flora. Their dominant grade must therefore be termed " very fine sand " rather than " coarse silt ". Incidentally, it should be noted that sediments possessing a mechanical composition similar to that of these sands are extremely rare amongst British deposits and comparatively rare (so far as our present knowledge goes) in those from abroad.

Excluding cemented samples or those with an admixture of soil, we find that the average composition of thirty-one samples from over the whole of the outcrop can be stated as follows :—

			%	
(VCS)	Very coarse sand	(> 1·0 mm.)	—	
(CS)	Coarse sand	(> 0·5 & < 1·0 mm.)	0·3	(Many ferruginous pellets in coarser grades.)
(MS)	Medium sand	(> 0·25 & < 0·5 mm.)	0·7	
(FS)	Fine sand	(> 0·1 & < 0·25 mm.)	7·4	
(VFS)	Very fine sand	(> 0·05 & < 0·1 mm.)	58·4	
(s)	Silt	(> 0·01 & < 0·05 mm.)	19·8	
(c)	Clay	(< 0·01 mm.)	13·4	
			100·0	

The analyses just averaged may be divided into two series, the members of each of which possess, within narrow limits, a very similar composition :—

(*a*) A series about twenty in number in which the very fine sand grade constitutes about 60 to 80 per cent of the deposit, and the silt about 20 to 10 per cent.

(*b*) A series about ten in number in which the very fine sand grade constitutes about 40 to 50 per cent and the silt about 35 to 20 per cent. This series is also, as might be expected, more clayey in character.

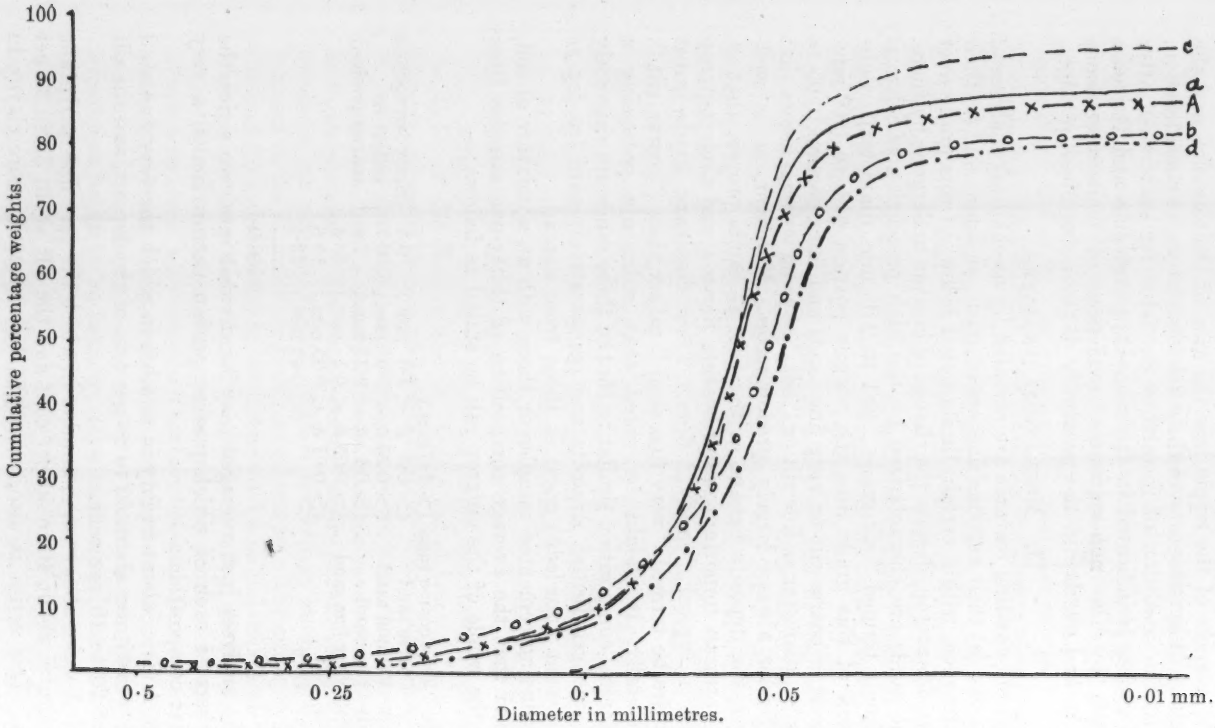

FIG. 1.—Graphical representation of mechanical analyses of sands from the Upper Lias and Inferior Oolite. A = average for all samples ; a = average for group (a) ; b = average for group (b). c = extreme sample from Yeovil ; d = extreme sample from Bridport.

The average composition of each of these series is as follows :—

	(a) %	(b) %
VCS . .	—	0·1
CS . . .	0·1	0·7
MS . . .	0·3	1·4
FS . . .	7·6	8·4
VFS . .	65·7	45·1
s . . .	15·6	26·4
c . . .	10·7	17·9
	100·0	100·0

A few analyses, typical of each group, together with the average analyses quoted above, are plotted as graphs in Fig. 1, and in the same diagram representations of the extreme examples are shown. Secondary minerals such as limonite (in pellets) or calcite (cementing grains) may modify several of the extreme analyses. It is probable that the mechanical composition of the sands over the whole area was originally even more uniform than is now apparently the case.

On plotting the mechanical composition with due regard to zones at different localities, no connexion between variation in grade and horizon is apparent. Such change as is found in mechanical composition seems to be quite arbitrary.

As the sands are traced eastwards and north-eastwards from Cheltenham, a change in lithology, as already noted (p. 248), sets in, accompanied also by a change in mineral constitution (III, p. 263). For example, the Northampton Sands of *scissum* zone at Tadmarton, Banbury, Corby, Northampton, etc., are comparatively coarse, whilst at Corby, Stamford and in Yorkshire estuarine clays also are found associated with or overlying the arenaceous deposits.

III. The Mineralogical Constitution of the Sands.

The general assemblage found in all samples of the sands, both from outcrops and boreholes, is similar and at the same time peculiar to the series of deposits so far as British sediments are concerned. Nevertheless, there are within limits certain differences in the proportion of constituent minerals which are useful as indicating the direction of derivation of the sediment.

An attempt was made to determine the variation in quantity of the heavy minerals with grade-size, but the difficulty of ensuring anything like complete separation in the silt and clay grades rendered the results valueless.

As compared with some British horizons, the variety of minerals which are abundant is not great. This lack of variety is compensated by the interesting features displayed by many of the heavy minerals.

Dr. H. H. Thomas has briefly described the chief constituent minerals (to the number of fourteen) of the sands from Broadwindsor (in L. Richardson, 12), and I have previously referred to

the mineral constitution of the deposits generally.[1] Sir J. J. H. Teall (6, p. 10) stated that in the residues of the Oolitic rocks he found quartz, oligoclase, plagioclase, rutile, tourmaline, garnet, and zircon, but did not refer to specific stratigraphical divisions.

The minerals now identified are as follows :—

Isometric.	*Tetragonal.*	*Rhombohedral.*
garnet.	anatase.	apatite.
magnetite.	rutile.	calcite.
pleonaste spinel.	zircon.	ilmenite.
[2]pyrite.		quartz.
[2]pyrrhotite.		tourmaline.

Orthorhombic.	*Monoclinic.*	*Triclinic.*
andalusite.		
brookite.	actinolite.	kyanite.
? chiastolite.	biotite.	microcline.
	chlorite.	oligoclase.
	chloritoid.	
? sillimanite.	epidote.	
	[2]glauconite.	
staurolite.	glaucophane.	*Other Minerals.*
? topaz.	hornblende.	chalcedony and chert.
		limonite.
	muscovite and other white micas.	serpentine.
	orthoclase.	
	sphene.	

Notes are added on the distinctive characters of some of the characteristic minerals, the order of treatment being approximately that of relative abundance.

Garnet is by far the most abundant constituent, so much so that the portion of the residue separated electro-magnetically is flesh-coloured or brown from its presence. Under the microscope, many grains are colourless, a few are pale pink, and many have a curious brown-pink tint. They are small (0·08 to 0·1 mm. diameter), exceedingly irregular in outline and angular. Crystalline form is practically never seen. The fracture is sub-conchoidal, giving rise in a large number of cases to re-entrant angles (Fig. 2). It is difficult to believe that such almost skeletal grains have travelled far in their present condition. Inclusions are on the whole rare; occasional minute crystals difficult to identify are visible.

Muscovite is very abundant in the form of relatively large colourless flakes (0·25 mm. to 0·4 mm. diameter), which have four to five times the average diameter of the other grains. The mineral frequently shows strain-shadows, thus revealing its derivation from metamorphic rocks. A pale greenish to colourless variety of mica with a very small optic axial angle (pseudo-uniaxial) occurs frequently, and usually appears in the electro-magnetic crop on separation.

Zircon (0·05 mm.) occurs in the usual variety of forms and tints.

[1] Geol. Mag., 1916, pp. 107, 108, 165.
[2] Found only in samples from boreholes.

It may be colourless, dusky with inclusions, or brownish to purple. It sometimes forms stumpy or needle-like prisms, but frequently occurs as sub-angular and rounded grains.

Magnetite (0·05 mm.) is usually abundant and may be extracted by means of a bar-magnet. Under the microscope, the grains are black and shiny, but not lustrous, and are frequently altered to limonite. They are mostly irregular in form, but crystal-faces are occasionally seen. The proportion of magnetite in the sands appears to decrease as they are traced southwards from the Cotteswolds, only a small quantity being observed in the South Dorset sediments.

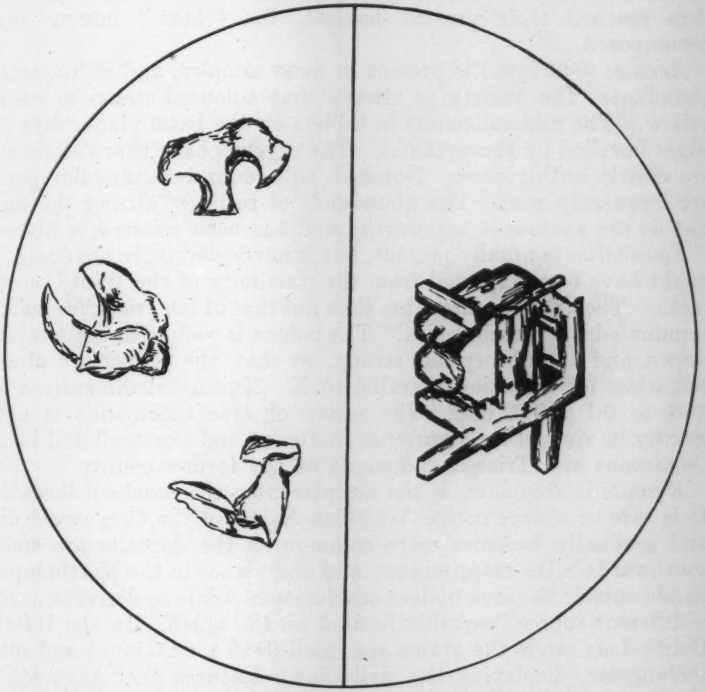

FIG. 2.—Garnet showing irregular form. × 150 diam.

FIG. 3.—Sagenite-rutile. × 225 diam.

Ilmenite (0·05 mm.) varies notably in quantity, but is always present. In some residues it is more abundant than garnet. The grains are irregular and of a lustrous black appearance. Many have been largely altered to leucoxene.

Rutile (0·05 to 0·07 mm.) is present in an unusually large proportion. Both the foxy-red and the yellow varieties occur, but the latter is much more abundant. Well-crystallized stumpy prisms, long needles, arrow-head twins, geniculate twins, irregular fragments,

and aggregates of crystals are all to be seen. The appearance of the aggregates is, except for the form, very like anatase. The similarity of colour and appearance suggests an inversion from anatase to the denser and probably more stable isomer, rutile. Much of the rutile (especially the deep foxy-red variety) appears to be ferriferous, and is extracted by the electro-magnet.

The delicacy and fragility of some of the needles and twins in such a detrital material is difficult to explain unless these crystals have been protected by a "host-mineral" during transport. Sagenite-webs, such as that indicated by Fig. 3, are not uncommon. Presumably they have been inclusions in biotite or chlorite and have thus reached their present habitat, the "host" having since decomposed.

Anatase (0·06 mm.) is present in most samples, and is frequently abundant. The variety is always that coloured straw- to lemon-yellow. The mineral occurs in tablets on the basal plane, with the edges bevelled by the pyramid. The crystals have sharp edges and are clearly authigenous. Notched, square and rectangular grains are frequently seen. The abundance of rutile of almost the same tint as the anatase is noteworthy and has been referred to above.

Tourmaline is usually present, but is never strikingly abundant, as might have been expected from the proximity of the West Country rocks. The habit is more often than not that of the prism, frequently terminated by rhombohedra. The colour is yellowish- to greyish-brown and the absorption strong, so that the grains are almost colourless for vibrations parallel to X. The usual dimensions are 0·08 to 0·1 × 0·02 mm. The rarity of blue tourmaline is noteworthy in view of its occurrence in Devon and Cornwall and in the Cretaceous and Triassic sediments of the former county.

Kyanite is abundant in the samples from the southern localities. It is rare or absent in the Whitbian Sands of the Cotteswold area and gradually becomes more common as the deposits are traced southwards. Its reappearance and abundance in the Northampton Sands outside the area under consideration points to derivation from a different source, probably located on the north. In the Inferior Oolite–Lias sands the grains are small (0·15 × 0·05 mm.) and often rectangular, displaying the well-known features that have led to the expression "of Lower Greensand habit". Frequently, however, they are frayed at the ends (Fig. 4), and some show strain-polarization. Occasionally the grains are almost square. The thinness of the flakes is indicated by the low interference-colours (1st order grey).

Staurolite is never very abundant. Like kyanite, it becomes more common as the beds are followed southwards. The small grains are angular and occasionally ragged (0·08 mm. diameter). The chips are so thin that only a very delicate dichroism in pale golden tints is observed.

Chloritoid.—A mineral which seems to be referable to the chloritoid group forms a persistent but not abundant constituent over the

whole outcrop.[1] It is most abundant and the cleavage-flakes are largest and thickest in South Dorset, but it becomes less plentiful as the sediments are traced northwards. The mineral occurs as scaly flakes, 0·08 to 0·15 mm. diameter, or wisps, the grains often consisting of several flakes partly superposed. A second cleavage at about 90 degrees to the almost perfect basal cleavage is sometimes seen running across the flakes, and a third cleavage occurs at about 70 degrees to the second cleavage. The average refractive index for sodium light, as determined by means of mixtures of mono-

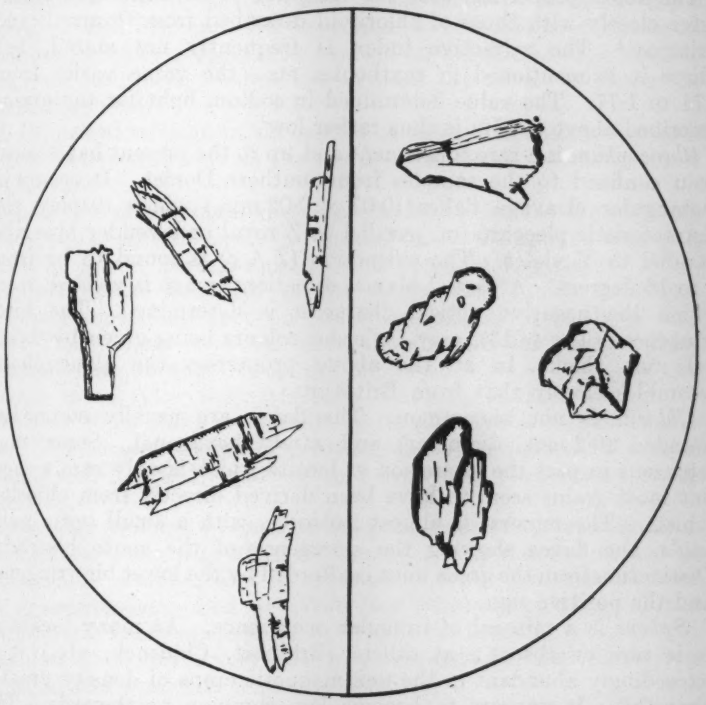

FIG. 4.—Kyanite. × 100 diam. FIG. 5.—Sphene. × 130 diam.

bromnaphthalene and methylene iolide is $> 1{\cdot}710$ and $< 1{\cdot}715$, but is nearer the former value. This figure is too high for an amphibole (for which the mineral may be mistaken) with the exception of arfvedsonite or riebeckite, the properties of which are different from those listed below. The pleochroism is distinctive, the absorption being moderately strong. The scheme is, parallel

[1] The identification of this mineral, which I had formerly passed over without proper examination as hornblende, is due to Mr. J. G. A. Skerl, who had first discovered it in the Northampton Ironstone and then searched for and found it in my slides from the south-western area.

to X (that is, approximately, second cleavage) dirty green or olive-coloured, parallel to Y indigo to smoky-blue. The wisps show less well-marked changes of colour. The birefringence is usually very low, ultra-blues, ultra-browns and indigo-tints being yielded; occasionally first order greys and yellows are seen. Most of the flakes give a biaxial figure, the emergence of the acute bisectrix being almost central. The sign is positive, and the isogyres frequently show well-marked dispersion. The wisps show straight extinction on the length.

The above properties, with the exception of the refractive index, agree closely with those of chloritoid described from Cornwall and Brittany.[1] The refractive index is frequently not stated, but where it is mentioned in textbooks, etc., the value varies from 1·74 to 1·77. The value determined in sodium light for the grains described above (1·712) is thus rather low.

Glaucophane is a rare constituent and up to the present has almost been confined to the samples from southern Dorset. It occurs in rectangular cleavage flakes (0·07 × 0·02 mm.) which display the characteristic pleochroism, parallel to Z royal or lavender blue and parallel to Y violet. The extinction (Z ∧ c) is found to be from 6 to 16 degrees. A partial biaxial directions-image is yielded, from which the negative optical character is determined. The birefringence is low (·013), grey 1st order colours being given by flakes 0·03 mm. thick. In all the above properties the glaucophane resembles closely that from Brittany.

Chlorite is not uncommon. The flakes are usually somewhat rounded (0·2 mm. diameter) and rarely hexagonal. Some may represent in part the alteration of biotite which is only rarely seen, but most grains seem to have been derived directly from chlorite-schists. The mineral is almost isotropic, with a small optic axial angle, the flakes showing the emergence of the acute bisectrix. Distinction from the green mica is afforded by the lower birefringence and the positive sign.

Sphene is a mineral of irregular occurrence. At many localities it is rare or absent; at others (Bridport, Chideock, etc.) it is exceedingly abundant in the non-magnetic crops of density greater than 3·3. It appears to become less common northwards. The grains are generally rather rounded (0·1 mm. diameter), but often possess characteristic projecting angles due to the cleavage (Fig. 5), and stand out in high relief by reason of their refractive index (1·9–2·0). Inclusions are frequent. The grains are colourless or faintly yellow-brown and non-pleochroic, therein resembling the sphene isolated by Dr. A. Brammall [2] from the Dartmoor granite;

[1] W. M. Hutchings, "On the occurrence of Ottrelite in the Phyllites of North Cornwall": GEOL. MAG., 1889, pp. 214–20; A. Lacroix, *Minéralogie de la France*, vol. i, 1887–1912, p. 366; C. Barrois, "Sur les schistes métamorphiques de l'île de Groix": *Ann. Soc. géol. du Nord*, vol. xi, 1884, pp. 18–71.

[2] *Mineralogical Mag.*, vol. xx, 1923, p. 22, etc.

the brighter yellowish tint and beautiful crystalline form displayed by the sphene found by Dr. R. H. Rastall in the Lower Greensand of Aspley Guise [1] are never seen. Under plane-polarized light and crossed nicols no extinction is observed, but a considerable variation in birefringence from " ultra-blue " to yellows or reds of the normal scale. The strong dispersion thus indicated is well seen in the directions-images with convergent light. The optical sign is positive. The only mineral for which the grains might be mistaken (on account of their high refractive index and dispersion) is brookite. The refractive index of the latter is, however, much higher (2·58–2·74), and the dispersion is of a different character (inclined in sphene, optic axes crossed in brookite). The vertical striations often seen on brookite crystals are never visible in the grains of sphene.

A reciprocal relation in the matter of relative abundance appears to exist between sphene on the one hand and anatase and brookite on the other.

Biotite is a rare mineral and seems to be confined to the southern part of the area. It occurs in rounded flakes, 0·2 mm. in diameter, brown in colour, pseudo-uniaxial and optically negative.

Apatite occurs as small prisms or rounded grains (0·08 mm. diameter) containing very fine dusty inclusions, probably of iron ores. The mineral is rather more abundant in the samples from boreholes than in those from the outcrop.

Green spinel (*pleonaste*), 0·05 mm. diameter, is rare.

Brookite (0·06 mm.) is sporadic in its occurrence and is usually rare. The straw-coloured or golden grains sometimes show crystal outlines and vertical striations and always display strong cross-dispersion.

Glauconite (0·2 mm.) occurs as irregular grains or relatively large foraminiferal casts (e.g. after *Nodosaria*). It is more abundant in the borehole samples, and is common at lower horizons, such as the pre-*margaritatus* bed at West Bay (Bridport). Some of the foraminiferal casts are altered externally to limonite.

Epidote (0·06 mm.), very faintly yellow-coloured and displaying the usual characters, is a rare mineral.

Andalusite (0·4 mm.) is also a rare constituent and has only been found in the Bridport and Gloucester districts. It occurs as relatively large ragged equidimensional grains, dusky with inclusions. The cleavage is well marked and the mineral displays characteristic salmon-pink pleochroism.

Calcite and *limonite* often form the cementing materials of the sands, the former sometimes appearing in the heavy residues as cleavage rhombs. Shell-fragments stained with iron oxide also occur. The calcareous content of the sand varies along the outcrop in a most irregular manner.

Pyrite, in cubical and octahedral grains (0·1 mm.), has been noted

[1] Geol. Mag., Vol. LVI, 1919, p. 267.

only in the samples from boreholes. *Pyrrhotite* in irregular bronze-coloured grains (0·1 mm.) has a similar occurrence. Although samples from the outcrop have been searched, these minerals have not been found therein.

Of the light crop, of density less than 2·8, *quartz* is the most abundant constituent (0·08 mm. diameter). *Orthoclase* felspar is also abundant, in the proportion of about one grain to eight of quartz, the grains being of about the same size. *Microcline* is frequently observed, but so far as "light" minerals alone are concerned, might be termed a rare constituent. *Plagioclase* felspar with lamellar twinning and an average refractive index greater than 1·540 and less than 1·5416, and therefore referable to *oligoclase*, is less often seen than microcline. Practically all the felspar grains are clouded with alteration-products.

The doubtful records of *topaz*, *chiastolite* and *sillimanite* are from very small and rare grains. *Common hornblende* occurs, but is a very rare constituent.

The outstanding features of the petrography of the deposits may now be stated as follows: (1) The great abundance throughout of garnet and pale micas, the former being usually colourless or pale-brownish and very irregular in form, and the latter including the uncommon pseudo-uniaxial variety; (2) the progressive increase in quantity of kyanite, staurolite, green and green-blue chloritoid, glaucophane and chlorite as the deposits are traced southwards; (3) the abundance throughout of titanium-bearing minerals, especially rutile,[1] anatase, and ilmenite, and the sporadic occurrence of brookite and sphene; (4) the abundance of orthoclase and mircocline; (5) the greater abundance underground of easily decomposable or soluble minerals such as ferrous compounds (which give the blue-grey tint to the sands as distinct from the yellow colour at the surface, a feature noted by Mr. S. S. Buckman (11)), pyrite, pyrrhotite, glauconite, apatite and calcite.[2]

In connexion with the occurrence of titanium minerals, the form and sharpness of the edges of the tablets of anatase indicate that it is authigenous. It has probably been derived from ilmenite, and brookite may have arisen in the same way. Much of the rutile seems to be detrital, but here and there the form of the grains or aggregates suggests a secondary origin after anatase or brookite. The mineral may also have arisen from the decomposition of ilmenite and sphene. Whilst it would be anticipated that the most stable form and therefore the end-product of polymorphic change would be the densest form of the oxide, rutile, there are published records of reverse change having taken place. The great similarity in colour

[1] E. B. Wethered noted abundant rutile in his residues from the limestones. "The Inferior Oolite of the Cotteswold Hills": *Q.J.G.S.*, vol. xlvii, 1891, p. 550.

[2] See, for example, the detailed description of the material from the Tetbury and Shipton Moyne boreholes (14, 15).

of the anatase, brookite and much of the rutile in these sands is noteworthy.

The content of titania in the sands is indicated in the following chemical analysis made by Dr. H. F. Harwood, of the Imperial College of Science and Technology :—

	%
SiO_2 . . .	85·22
Al_2O_3 . . .	6·93
Fe_2O_3 . . .	1·39
MgO . . .	0·37
CaO . . .	0·96
Na_2O . . .	0·73
K_2O . . .	1·99
TiO_2 . . .	0·52
H_2O . . .	2·01
Cl . . .	0·55
	100·67
Less O for Cl . .	0·12
	100·55

Possible Source of the Minerals.

Of the minerals noted above, kyanite, glaucophane, microcline and pseudo-uniaxial mica have not been recorded with certainty in the pre-Jurassic rocks of the West Country. Brownish-pink garnets like those described on p. 252 have been observed in the ancient rocks of the Lizard.[1] The rose-pink, orange-pink, and colourless varieties may have been derived from either the metamorphic aureoles of the West Country or an old land-mass of which Brittany formed part. Whilst the abundant orthoclase may have been derived from the granites and elvans of Cornwall and Devon, microcline could only have been yielded by pre-Cambrian rocks farther south or south-west. The igneous and metamorphic rocks of the West of England might have yielded, besides oligoclase, orthoclase and garnet, such minerals as magnetite, spinel, zircon, rutile, apatite, ilmenite, tourmaline, epidote, chloritoid, muscovite, etc. Turning from the crystalline rocks to the sediments, it is to be noted that the land-mass bordering the Lias–Inferior Oolite sea on the west was constituted of Triassic, Permian, Carboniferous, and Devonian rocks.

The heavy residues of the Jurassic rocks of this area are notably different from those of the Trias as investigated by Dr. H. H. Thomas,[2] the chief points of difference being the presence of unaltered kyanite, chlorite, blue-green chloritoid, glaucophane, brownish garnets, pseudo-uniaxial mica, and the absence of fluor, topaz, cassiterite, etc., in the Jurassic sediments. Staurolite, which is common to both Triassic and Jurassic sands, is hardly plentiful

[1] "The Geology of the Lizard and Meneage": *Mem. Geol. Surv.*, 1912, p. 208.

[2] *Q.J.G.S.*, vol. lviii, 1902, p. 620; vol. lxv, 1909, p. 229.

enough even in the New Red Sandstone of Dorset to render derivation from that formation probable. It is rare in the metamorphosed rocks of the West of England. The extreme abundance and persistence of garnets in the Jurassic sands is in marked contrast with their irregular occurrence in both older and newer sediments in the West of England and France.

The Permian sandstones of the West of England contain bright red garnet, tourmaline, zircon and rutile as abundant constituents, and, more rarely, staurolite, topaz and glaucophane.

The characteristic minerals of the Pennant Series [1] of the Bristol district are garnet, chlorite, green hornblende, muscovite (with strain-polarization), brown tourmaline, rutile, zircon, ilmenite, kyanite (rare), anatase, cordierite (?), etc. The petrography of rocks of the same age from the Cardiff district has recently been described by Mr. A. Heard.[2] The minerals he records include cordierite, rutile, zircon, muscovite, corundum, biotite, tourmaline, chlorite and fluorite.

The Old Red Sandstone of the Welsh Borders contains abundant garnet, chlorite, mica, topaz (?), tourmaline, ilmenite, rutile, zircon and epidote, but as Dr. Thomas has pointed out (12, p. 71) there is nothing to suggest derivation of the Jurassic sands from this formation.

Our acquaintance with the petrology of the arenaceous members of the neighbouring Devonian, Carboniferous, Permian, and Triassic rocks, therefore indicates that whilst pink garnet, chlorite, and mica may have been contributed by the Old Red Sandstone and the Pennant Series, and garnet by the Permian and Trias also, denudation of these rocks would not alone yield the mineral assemblage of the Jurassic rocks under consideration.

If we turn to Brittany, regarding that area as a remnant of the old Armorican land-mass which has been so much drawn upon to explain the presence of stress-minerals in the Mesozoic and Tertiary sediments of the West of England, we find abundant microcline, staurolite, kyanite, garnet, glaucophane, epidote, sphene, rutile, andalusite, chloritoid and chlorite-bearing metamorphic rocks.[3] The association, in particular, of glaucophane, chloritoid and epidote in the rocks of Île de Groix and Morbihan is well known. The nearest source for those minerals in the Jurassic sands is such an area, and the decrease in abundance of some of them northwards as the distance of the sediment from this area increases, lends confirmation to this view of a south-westerly origin.

During Liassic times the margin of the sea, which according to

[1] I am indebted to Professor S. H. Reynolds for samples of the Pennant Sandstones of the Bristol Area from both outcrops and a borehole.

[2] GEOL. MAG., Vol. LIX, 1922, pp. 83–92.

[3] A. Lacroix, *Minéralogie de la France*, 1887–1912; T. G. Bonney, "Note on the Structure and Relations of some of the Older Rocks of Brittany": *Q.J.G.S.*, vol. xliii, 1887, p. 301; C. Barrois, "Sur les schistes métamorphiques de l'Île de Groix": *Ann. Soc. Géol. du Nord*, vol. xi, 1884, p. 18.

the French geologists [1] ran approximately north and south through Wales and then swung eastwards by the eastern coast of the Cotentin, was retreating eastwards until in Inferior Oolite times it ran a little west of north from the Cotentin through Dorset to the line of the present Severn. The Welsh area, Devon, Cornwall, and Brittany must have drained into this sea-basin and provided the sediments here described. As already noted, the Palæozoic and Triassic rocks of the British area were not an adequate source for the minerals under discussion, and the difference in mineralogical character of the Cretaceous and Tertiary deposits of Devon and Cornwall [2] and those of either the Trias or Jurassic rocks renders it probable that the rocks exposed in the area of the West of England were not of the same character in early Mesozoic as in Cretaceous and Tertiary times. The land occupying the present site of the English Channel and including the Start and Lizard promontories and Brittany was the most likely source of the minerals described, and the fact that the latter reached as far north as Wiltshire and Gloucestershire points to current-drift northwards along the coast.

The investigation of the petrology of the littoral Lias of South Wales would doubtless throw some light on the source of its detrital material. The study of the calcareous deposits shows the extent to which the life of the sea was influenced by the proximity of the Carboniferous Limestone.[3] The latter formation may also have been the source of much of the calcareous substance of the Inferior Oolite.

In seeking for a south-westerly source for the Upper Lias and Lower Inferior Oolite of the Dorset-Gloucestershire area, we naturally turn for comparison to the Domerian, Toarcian, and Aalenian sandy deposits where they transgress in Calvados on to the old Armorican ridge. Amongst the type-sections, which have long been known, are those of May-sur-Orne, near Caen, and Bayeux. In this neighbourhood the Ordovician Grès de May itself contains muscovite, tourmaline, zircon, anatase, rutile, brookite, sphene, microcline, orthoclase, etc., but no garnets. The matrix of the Domerian conglomerates contains, notably, red garnet, anatase, rutile, zircon, iron ores, brown tourmaline, brookite, green hornblende, microcline, and mica. The Aalenian sands contain in addition richly pleochroic hypersthene.

These assemblages cannot be regarded as throwing much light on the British deposits. Many of the characteristic Armorican minerals are absent, and it would seem that the source of those which occur was local and in part lay in pre-existing sediments, that is, those occupying the eastern portion of the Breton mass. On the other hand, the British deposits had a more westerly or south-westerly

[1] E. Haug, *Traité de Géologie*, vol. ii, pt. ii, 3rd ed., 1921, pp. 952, 996; A. Bigot, *Bull. Soc. Géol. France*, ser. iv, vol. iv, 1904, pp. 861–908.

[2] *Q.J.G.S.*, vol. lxxix, 1922, pp. 205–29.

[3] A. E. Trueman, *Proc. Geol. Assoc.*, vol. xxxiii, 1922, p. 245.

source, in metamorphic rocks, the drainage from which swept directly northwards.

Summary.

The main conclusions of the paper may be briefly stated thus :—

1. The deposits, which are of neritic facies, possess a characteristic and peculiar mechanical and mineralogical composition, differing therein from any other British deposit.

2. They exhibit a general constancy in grade from the Dorset coast to the Cotteswolds. Within this limit they conform to two chief types containing respectively 40 to 50 and 60 to 80 per cent. of the very fine sand grade (greater than 0·05 and less than 0·1 mm.). No variation of mechanical composition with hemeral change can be observed.

3. The sands are blue and glauconitic in depth. At the surface they are decalcified and are yellow and brown as a result of oxidation. Minerals such as pyrite and pyrrhotite occur only in depth.

4. The mineralogical composition indicates an abundance of highly angular brownish-pink to colourless garnets (possibly derived from rocks like those of the Lizard), but few red or purplish-red varieties ; also of micas (including a pseudo-uniaxial, pale-green to colourless variety), together with chlorite, chloritoid, kyanite, staurolite, orthoclase, and microcline.

5. Tourmaline is only moderately common and is always the grey-brown variety.

6. The abundance of titanium-minerals is characteristic of the deposits. Red and yellow varieties of rutile and sagenite-webs are exceedingly abundant, and anatase, brookite, and sphene are locally so. A reciprocal relation may exist between the occurrence of sphene, ilmenite, and the oxides of titanium.

7. Epidote and glaucophane are rare.

8. Chlorite, chloritoid, glaucophane, kyanite, and staurolite increase in quantity as the deposits are traced southwards.

9. A change in lithology and mineralogy sets in as the deposits are followed north-eastwards into the Midlands and Yorkshire.

10. The sands differ markedly in petrology from the various Palæozoic rocks of Wales and the West Country, from the Trias, and from the Cretaceous and Eocene of Devon and Dorset.

11. The Ordovician, Domerian, Toarcian, and Aalenian of Normandy and Brittany have been examined petrologically for purposes of comparison, but show little resemblance to the sediments under discussion, having been derived locally from the Palæozoic and pre-Cambrian rocks.

12. It is concluded that the Lias–Inferior Oolite sands have been derived from the south or south-west, notably from rocks like those of western Brittany.

13. The rise of the Mendip axis was not sufficiently complete at this time to cut off the supply of sediment from the south or south-

west. The deposits north and south of the ridge have the same general character.

In conclusion, I desire to express my cordial thanks to Professor A. Bigot, of the University of Caen, for conducting me over the Calvados sections, and to Dr. E. Neaverson and Mr. J. G. A. Skerl, of the University of Liverpool, for their company and assistance in the field abroad and at home respectively. Mr. Skerl has also assisted with much of the laboratory work. I am especially under a debt of gratitude to Mr. S. S. Buckman and Mr. Linsdall Richardson (without whose detailed zonal work this paper would necessarily have lacked precision) for their ever-ready advice and help. Moreover, both those gentlemen have kindly read the manuscript and made many valuable suggestions.

TABLE OF HEAVY MINERAL OCCURRENCES.

(*Only representative localities are included.*)

	Gloucester.	*Painswick.*	*Dursley.*	*Wotton.*	*Sodbury.*	*Midford.*	*Bruton.*	*Compton Pauncefoot.*	*Yeovil.*	*Broadwindsor.*	*Beaminster.*	*Bridport.*
Garnet	10	10	10	10	10	10	10	10	10	10	10	10
Magnetite	8	8	8	8	7	4	5	5	4	3	3	2
Spinel (pleonaste)	—	—	—	—	—	1	—	—	1	—	—	1
Anatase	—	—	2	—	2	1	—	4	8	1	2	2
Rutile	10	10	10	10	10	10	10	10	10	10	10	10
Zircon	10	10	10	10	10	10	10	10	10	10	10	10
Apatite	—	—	—	—	—	—	—	—	7	3	3	4
Ilmenite	8	8	7	8	5	8	7	5	5	4	5	5
Tourmaline	7	8	7	8	5	6	8	6	5	5	5	6
Andalusite	1	—	—	—	—	—	—	—	—	—	—	1
Brookite	—	—	—	—	3	3	—	—	1	—	2	—
Staurolite	3	1	1	3	2	7	2	7	3	5	7	8
Actinolite	—	—	—	—	2	—	—	—	—	—	—	3
Biotite	—	—	1	—	—	—	—	—	—	—	1	2
Chlorite	2	4	3	3	2	3	—	3	8	—	10	8
Chloritoid	5	2	3	3	3	3	5	5	6	3	6	6
Epidote	—	—	1	—	1	—	—	—	—	1	1	1
Glaucophane	—	—	—	—	1	—	—	—	2	—	—	2
Hornblende	1	—	—	—	—	—	—	—	1	1	—	1
Muscovite	10	10	10	10	10	10	10	10	10	10	10	10
Serpentine	—	—	—	—	—	—	—	—	—	—	—	2
Sphene	—	—	—	—	—	—	—	—	1	—	3	5
Kyanite	3	1	—	2	2	8	1	1	1	5	7	8

1 = exceedingly rare; 2 = rare; 3 = very scarce;
4 = scarce; 5 = frequent; 6 = very frequent;
7 = abundant; 8 = very abundant; 9 = dominant;
10 = ultra-dominant.

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Notes on the Glaciation of the Coniston Fells.

By Professor J. E. Marr, F.R.S.

I HAVE for several years paid attention to glacial phenomena near Coniston, and some of my observations seem to be worth recording.

I. Asymmetrical Hill-outlines.

The well-known lack of symmetry of the hill outlines is well displayed on the Coniston Fells, the gentler convex slopes of which face westward, while the steep concave slopes are on the east side. This asymmetry was noted in the Cuillin Hills by Harker,[1] who mentions that it is connected "with the direction of incidence of solar radiation". Gilbert [2] explains this phenomenon by suggesting that since the ice surface is lowered by melting on the east and north sides of the valleys, there would be a lateral flow of ice in that direction. This would, on his hypothesis, cause a lateral crevasse to develop in the shaded slope. The presence of this lateral crevasse has, however, yet to be demonstrated.

In my *Geology of the Lake District*, p. 160, I suggested a possible

[1] A. Harker, *Trans. Roy. Soc. Edin.*, vol. xl, pt. ii, No. 12, 1901, p. 240.
[2] G. K. Gilbert, *Journal of Geology*, Chicago, vol. xii, 1904, p. 579.

reason for this feature. "On the sunny side melting of the ice might take place to so great an extent that the proportion of morainic material held in the ice became large enough to check the power of corrasion of the ice, which would therefore corrode laterally and downward on the shaded side only." I should have said as regards downward corrasion, that it was *chiefly* instead of *only* on the shaded side. I wish here to enlarge upon this suggestion. The operation of the ice can be made clear by reference to the diagram (Fig. 2).

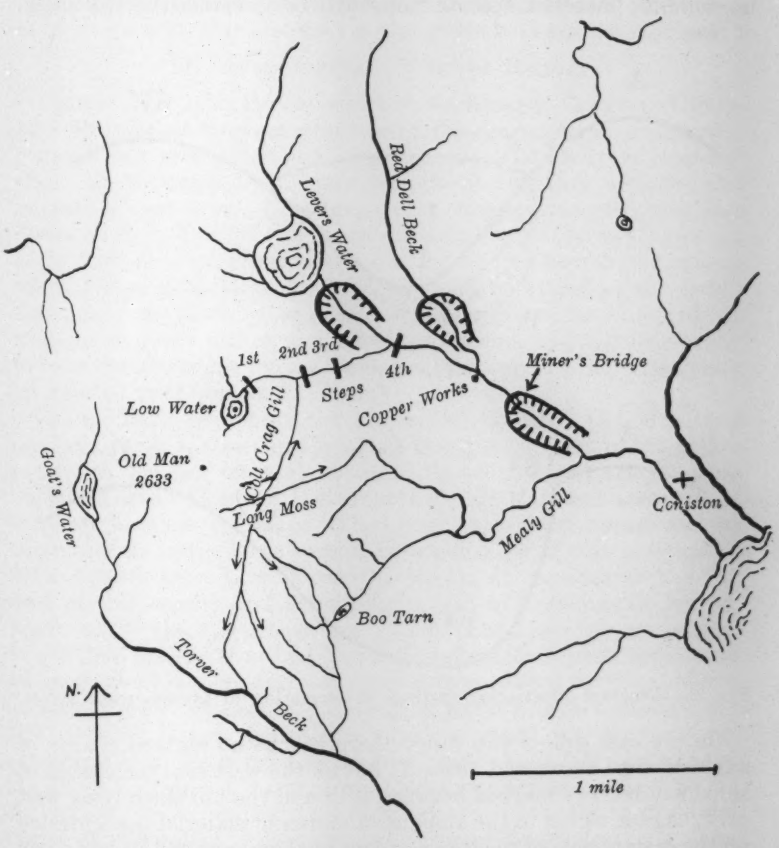


FIG. 1.—Sketch-map showing chief glaciated gorges, steps, and general drainage on Coniston Old Man.

The preglacial outline of mature relief of two hills and an intervening valley is represented by the continuous line. The upper surface of the ice occupying the valley during the final stage of glaciation is shown by the broken line (ST). This upper surface will be gradually lowered as downward corrasion proceeds. Owing to the greater

melting of the ice near T, downward and lateral corrasion will be here at a minimum, while both downward and lateral corrasion will be most pronounced at the western side of the valley at S. Accordingly corrasion will proceed from the initial stage, ASPTB, to carve out the valley in the manner represented by the dotted lines S^1P^1T, S^2P^2T, S^3P^3T. The ultimate outline of the surface (after the melting of the ice) will be AS^3P^3TB. It will be noted that the part above the ice will be affected by frost action where not protected by morainic material and its slope will be governed by the angle of rest.

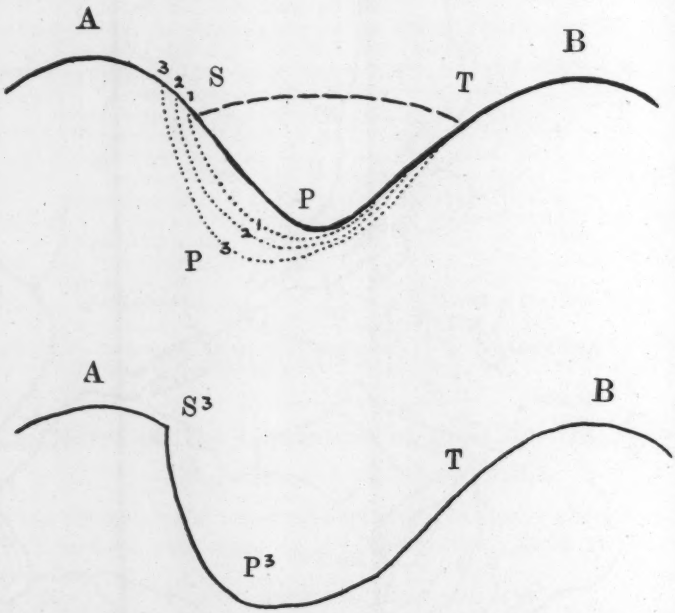


FIG. 2.—Diagram illustrating method of formation of asymmetrical slopes.

On the east side of the valley there will be no marked change of angle of slope above and below T, but on the west side the change of slope will be very marked between S^3P^3 and the hill slope lying west of S^3. Again, owing to the amount of morainic material concentrated on the eastern side of the ice an exceptional amount will be laid down as lateral moraine on this side and will accumulate at lower levels as the ice surface recedes downwards. This is actually seen on many of these western-facing slopes, while the lateral corrasion on the west side of the valley will remove the lateral moraine from this slope. This morainic material will keep the percolating waters against the underlying rocks, which will tend to undergo much greater weathering than the drift-free rocks on the west side of the valley.

These, furthermore, will have been exposed to weathering action for a shorter period than, at any rate, the higher parts of the slope on the east side.

The action is comparable in a general way with the cutting of a stream at a bend with lateral corrasion of a steep bank on its concave side and a flat part with alluvium at the convex one, though the diminution of the energy for downward corrasion is, of course, due to different causes. It should be noted that though on the east side of the Coniston Fells the asymmetry is emphasized by the action of corrie glaciers, it is also seen in the tracts between the corries.

II. Interglacial (?) River Gorges.

Church Beck, the stream which flows through Coniston Village, with its tributaries gives evidence of the formation of water-worn gorges which were subsequently glaciated. The study of erosional effects as throwing light upon periods of alternate advance and retreat of ice was, I believe, first entered on by the late Professor R. S. Tarr. I called attention to this matter in my *Geology of the Lake District*, chapter xix, but did not notice the phenomena which I here propose to describe. It may be stated at the outset that more satisfactory evidence will doubtless be obtained by studying deposits rather than effects of erosion, and it is interesting to note the discovery by the Geological Surveyors of an apparently interglacial peat-bed at St. Bees.[1]

Church Beck rises near the summit of Coniston Old Man, and descends, with a steep grade along the greater part of its higher course, to the flat tract at the head of which stand the Coniston Copper Works. Between the summit of Old Man and these works there are four marked steps. The upper part of the stream and its tributaries is in the large combe, in which Low Water is situated. After flowing from Low Water the stream at once leaves the flat floor of this combe and leaps over a cliff of considerable height, which marks the uppermost step. Each of the four steps is of less height than the one above it. The cliffs extend far beyond the stream which flows over them and were probably produced by the plucking action of the ice. On reaching the copper works a flat is encountered ; this is much larger than those which separate the above steps, extending from the copper works to a point about 150 yards above the Miner's Bridge, a distance of about one-third of a mile. So far the steps we have considered are ordinary steps along the longitudinal course of the valley ; the next one shows different features. The hanging valley above the Miner's Bridge mouths at about 550 feet. From this place the stream descends in cascades and waterfalls to a point where Mealy Beck enters the main stream, where the latter again assumes a flatter course. Its height at the junction of Mealy Gill is 250 feet, so that it has fallen 300 feet in the course of the 650 yards between the mouth of the hanging valley and the entrance

[1] " Summary of Progress for 1921 " : *Mem. Geol. Surv.*, 1922, pp. 67, 68.

of Mealy Gill. The valley between these points differs in a marked degree from the stretch above the mouth of the hanging portion. Above it is a wide canal-like valley of mature glacial aspect, below it is much narrower and gorgelike, and strongly resembles in a general way an ordinary water-worn gorge. That this was its origin was recognized by Messrs. Grace and Smith.[1] The significant feature is that since the gorge was eroded it has been glaciated to a depth at least 290 feet below the point where the valley now mouths above the Miner's Bridge. The glacial striae which run parallel with the valley are well seen near the above-mentioned bridge.

The fluviatile character of the gorge forbids the supposition that we are dealing here with a step resembling those higher up stream, and points to water-erosion of the downward end of a hanging valley which once mouthed about 660 yards south-east of the point where it now does so. Consequently between the first glaciation which produced the hanging valley and the second glaciation which followed the water-erosion a gorge of over 700 yards was excavated to a depth in places of about 200 feet, and probably more. This indicates, at any rate, a considerable period of ice-retreat, though not necessarily complete disappearance. Since the second glaciation the ice-modified gorge has again been deepened to some extent by water-erosion. The amount varies in different places, as the stream here is far from grade, but it seems in no case to be very great.

It should be noted that there is evidence of little deepening by the main ice of the Coniston Valley during the second period of glaciation, for no marked hanging valley occurs between Mealy Beck and the lake.

Similar features are seen where the Levers Water and Red Dell Becks enter the Church Beck Valley. The case of the Red Dell is very interesting. It is one of the most marked hanging valleys of the district. It now mouths at a height of 925 feet at a distance of 320 yards from its junction with the Church Beck Valley, and in this distance it falls about 265 feet. This part of the valley presents the outline of a water-eroded gorge, but, again, as in the part of Church Beck described above, it has been modified by ice-action, the direction of the ice being parallel with this part of the valley. Well striated "roches moutonnées" are seen at the lower end of the valley nearly down to stream level and the amount of erosion produced by the stream since the last ice-advance is only a few feet. The same features are seen in the valley of Levers Water Beck, but not so strikingly exhibited.

The phenomena as described certainly point to water-erosion causing the cutting back of gorges up valley from the original mouthing points. There remains, however, the possibility that this was done by sub-glacial streams eroding below the ice and causing the ice to sag down into the valley.[2]

[1] G. Grace and F. H. Smith, *Proc. Yorks Geol. Soc.*, vol. xix, 1921–2, pp. 408–9.

[2] See Garwood, *Q.J.G.S.*, vol. lviii, 1902, pl. xl, fig. 2.

III. On Certain Stream Courses.

Many overflow channels are found in the neighbourhood of Coniston, some of which have been described elsewhere. There are, however, two depressions containing streams on the southern slopes of Old Man which deserve notice. Boo Tarn is situated in the depression of the Stockdale Shales and this depression slopes from it in a north-easterly direction to Mealy Gill, and so to Church Beck, and in a south-westerly direction to Torver Beck. North-west of this and higher up the slopes are similar depressions starting from Long Moss and extending a few degrees east of north to Church Beck and in the opposite direction to Torver Beck. The northerly depression is partly occupied by a stream, Colt Crag Gill, and the southerly one by a nameless stream. The depressions lie along a line of shatter belt, apparently along a fault which shifts the Coniston Limestone on Flask Brow to the south.

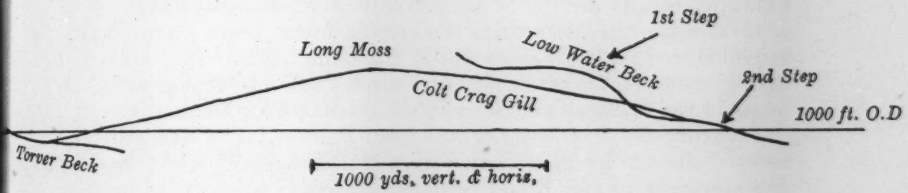


Fig. 3.—Central line shows graded valleys draining from Long Moss contrasted with ungraded slope of Low Water Beck (right-hand line). Profils drawn to same horizontal and vertical scale.

Some tributaries flowing on to each are diverted along the depressions, but notches on the other side of these depressions mark sites where the tributaries flowed across before diversion. Some of these tributaries are now being restored to their original channels by delta-building across the depressions, and in two cases by artificial cuts. The original diversions might be supposed to be due to ordinary capture by strike streams in the case of the Boo Tarn hollows and along the shatter-belt in the other case, but this seems to be negatived by the remarkably regular grade of the floor in the depressions. From Long Moss the depressions are uniformly graded in both directions at an angle of 14 degrees until they reach Church Beck and Torver Beck respectively. That they existed in glacial times is shown by the occurrence of drift on the floors, and it may be suggested that the depressions were made by glacial action, probably in the first place by glacial erosion of the soft rocks of the depression aided later by water from melting snow and ice flowing into the depression from above, and thus deepening them. The large volume of water entering at the sources would account for the even grade.

I desire to thank Mr. W. B. R. King, M.A., for his kindness in drawing the diagrams accompanying this paper.

A "*Woodocrinus*" Fauna from the Scottish Border.

By James Wright.

(PLATES XIII–XVI.)

THE majority of the crinoids recorded in this paper are from Penton Linns and a few from Harelawhill and Peterscrook in Liddesdale on the Scottish border. Peterscrook is really on the English side of the Liddel, which here forms the border line, but being quite a short distance from the other localities, it is thought advisable to include it here. The specimens in my own collection are the result of five visits at various times during recent years, the first of which, in the autumn of 1920, I was accompanied by my lamented friend, the late Mr. Robert Dunlop. My companion on the three following visits was Mr. James L. Begg, of Glasgow, and on the fifth visit Mr. J. G. Duncan, late of the Royal Scottish Museum and now of Kirkcaldy. To our combined efforts the following results are due. An account of these results may be of interest more especially since the crinoid fauna bears a remarkable resemblance to the "*Woodocrinus*" fauna discovered many years ago at Richmond in Yorkshire and first made known to geologists in the pages of the *Geologist* and later in the Geological Magazine.

Probably the first *Woodocrinus* from Penton Linns was collected many years ago by Miss Donald (now Mrs. Longstaff), who presented the specimen to the Royal Scottish Museum, where it is now on exhibition. About the year 1905 or 1906 Messrs. John Smith and Robert Dunlop visited Penton Linns, accompanied by Mr. Arthur Macconochie of the Scottish Geological Survey, and Mr. Dunlop was fortunate enough to find a fairly complete specimen of *Woodocrinus*. Thinking that the locality might repay an extended search, Mr. Dunlop and I often discussed the possibility of giving it a trial, but it was not till the autumn of 1920 that our desire was realized. On this visit we were fortunate so far in finding a few crinoids, but we were not successful in tracing the layer in which these fossils occur. The following year, Mr. Begg and I, after removing the overlying shales, fixed the exact line occupied by the crinoids and on this occasion, as well as on our later visits, were rewarded by an interesting series of specimens.

So far as our observations go, the crinoids occur in a single layer in the calcareous shales which overlie the thick limestone of the Penton Linns gorge. The limestone is of Lower Carboniferous age and probably on or about the same horizon as the so-called "Hurlet" of central Scotland and Fife. The position of the crinoid layer is about 3 feet above the limestone and 6 inches or thereby below a hard limestone band which is a prominent feature in the shales on the river bank. The best outcrop for working is seen a few hundred yards south of Penton bridge, where both limestone and shales cross the Liddel with a gentle dip to the south, and are not disturbed as they are to the north of this point. The exposure of the shales on

the English side is, however, much obscured by talus, and after examination we abandoned these beds as they offered little scope for digging. The Penton crinoids here recorded were therefore all found on the Scottish bank.

During the course of our operations, we took out many cubic yards of shale and, as at most crinoid localities, found the specimens as single individuals. Sometimes, however, two or three would be found together (see Pl. XIV), thereafter several square feet would be barren. The crinoid layer itself is full of the shells of *Productus longispinus*, under which lies another layer full of *Spirifera trigonalis*, and this often helped us in following it out. Our method of working was to clear away the overlying shales down to a few inches of the crinoid layer. If a portion of stem was observed we carefully removed the shale surrounding it and followed it to its end, where, if fortunate, the crown of the crinoid was found in position. This method we generally found to yield good results since, unlike the majority of shales overlying a limestone, detached ossicles or dismembered portions of stems are in this layer comparatively rare. A very rich marine fauna characterizes the whole group of shales here and a good list of these fossils is given in Peach and Horne's paper on the Canonbie coalfield (*Trans. Roy. Soc. Edin.*, vol. xl, pt. iv, No. 32, 1903).

So far as present knowledge goes, the total number of crinoids found at Penton Linns must comprise over forty-five specimens. Of these some twenty-five belong to *Woodocrinus*, eleven to *Ulocrinus*, two to *Poteriocrinus*, two to a *Poteriocrinid*, about which I can get little information, two to *Eupachycrinus*, and two to *Onychocrinus*. The remainder are not yet developed. Of the specimens of *Woodocrinus*, one is in the Royal Scottish Museum (Geological Department), one in the Dunlop Collection, Pittencrieff House, Dunfermline, six in Mr. James L. Begg's collection, and fifteen in my own collection. In Peach and Horne's paper already referred to, three species of crinoids are given in the list of fossils from Penton Linns. The specimens are in the collection of the Scottish Geological Survey in George Square, Edinburgh, and will be referred to later. All the other specimens not mentioned here are in my collection.

As may be noted from the figures given above, *Woodocrinus* is the most prevalent crinoid at Penton. Most specimens agree fairly well with the *Woodocrinus macrodactylus* of de Koninck (*Geologist*, vol. i, No. 1, 1858). There are, however, two which do not come under the description of that species, and probably another one, but it is not yet fully developed. One, No. 2173 J. W. Colln. (Pl. XIV) is a large flattened crown with about 14 inches of the stem in place. The arms in their connexion with the cup are somewhat obscure, but are noticeably longer than the usual *W. macrodactylus* type and are not quite so heavy and rounded. The branching in one of the exposed rays is also irregular, and the stem does not appear to taper away so quickly (cf. Pls. XIII and XIV). Until it is properly worked out, it will meantime be recorded as *Woodocrinus* cf. *macrodactylus*.

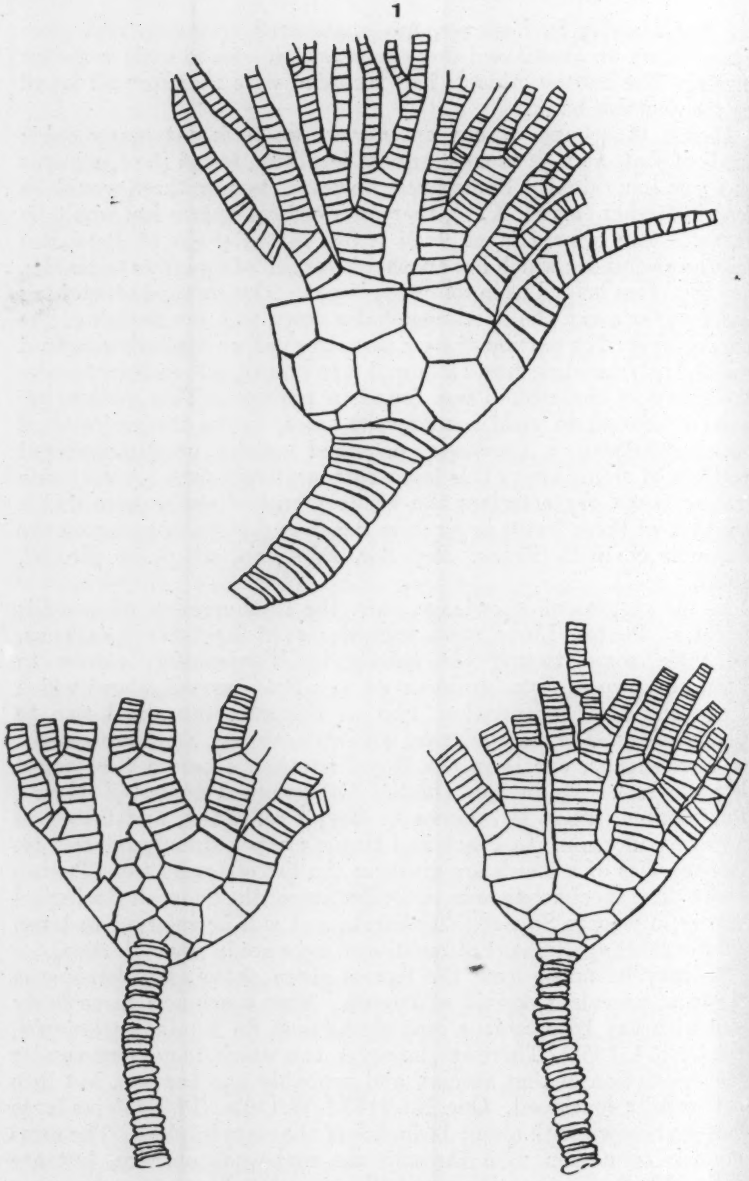


FIG. 1.—*Woodocrinus expansus* de Kon. Tracing of specimen figured by Roberts, GEOL. MAG., Vol. II, 1865, p. 163.

,, 2.—*Woodocrinus* cf. *expansus* de Kon. Penton Linns, Liddesdale. Specimen No. 2105, J. Wright Colln. Posterior view. Nat. size.

,, 3.—Same specimen, anterior view. Nat. size.

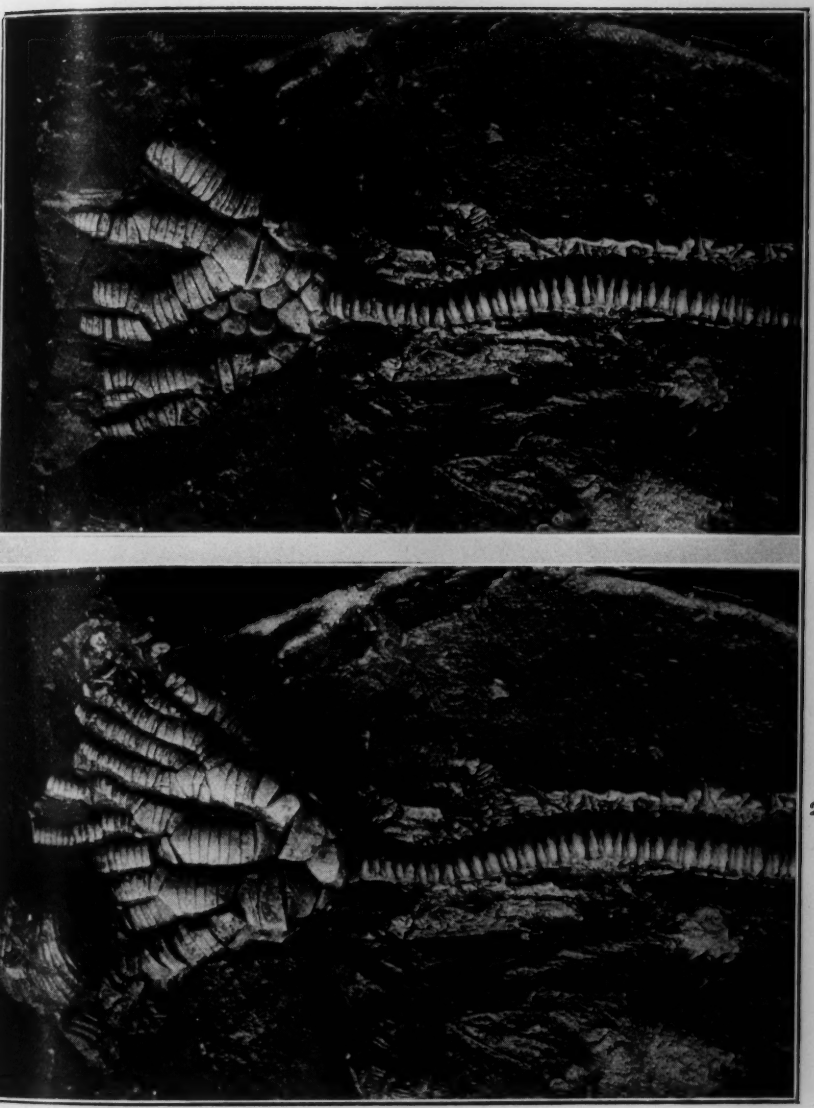
J. Wright photo.

WOODOCRINUS MACRODACTYLUS DE KON. FROM PENTON LINNS.

To face p. 272.]

J. Wright photo.

WOODOCRINUS CF. *MACRODACTYLUS* DE KON. FROM PENTON LINNS.



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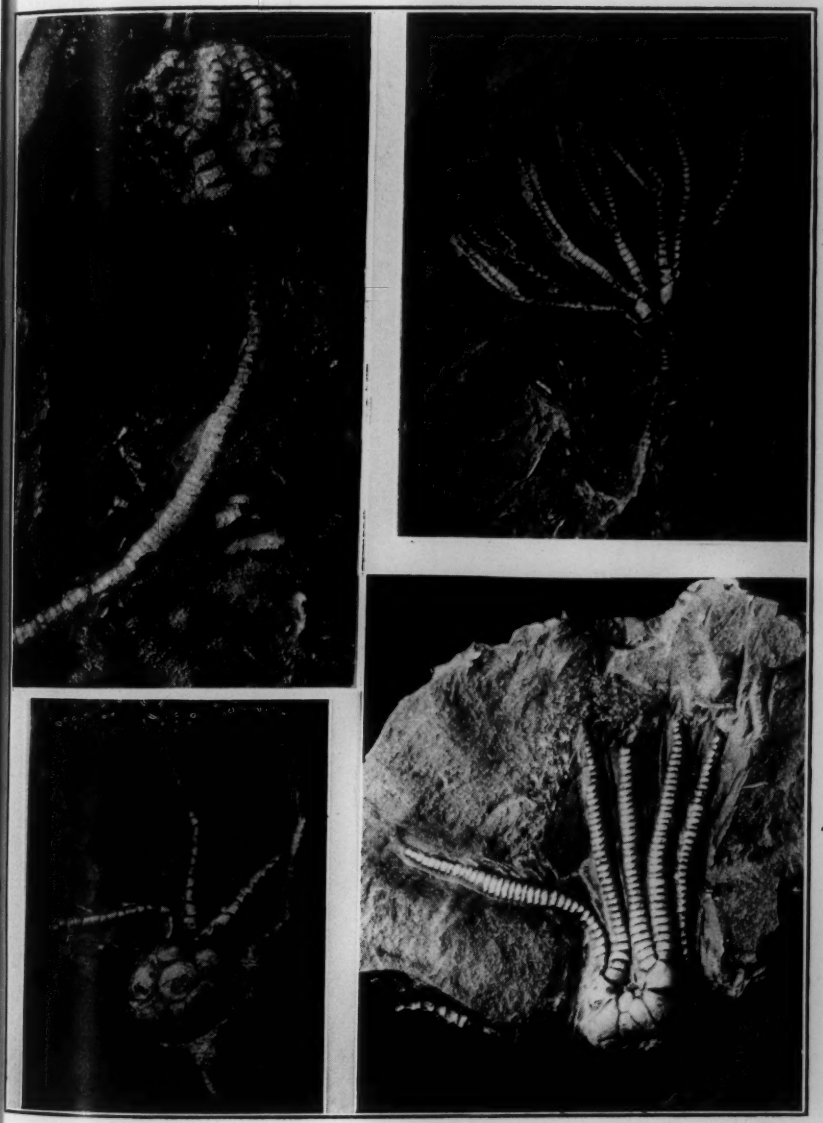
WOODOCRINUS CF. *EXPANSUS* DE KON. FROM PENTON LINNS.



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J. Wright photo.

CRINOIDS FROM PENTON LINNS.

The other specimen, No. 2105 J. W. Colln. (Text-figs. 2, 3, and 4, Pl. XV) has a general resemblance to the figure of *Woodocrinus expansus*, de Koninck, given by Roberts in GEOLOGICAL MAGAZINE, Vol. II, 1865, p. 163 (Text-fig. 1 of present paper). A comparison shows certain differences among which are the following :—

(1) In Roberts' figure, the BB appear to be relatively longer and higher, and perhaps also the RR.

(2) The IBr (IAx) are low in height and small in relation to the RR. In specimen No. 2105 these plates are about equal in height to the RR and of about the same size, except in the anterior ray, where there are two IBr. In the right antero-lateral ray of No. 2105 the plate is missing.

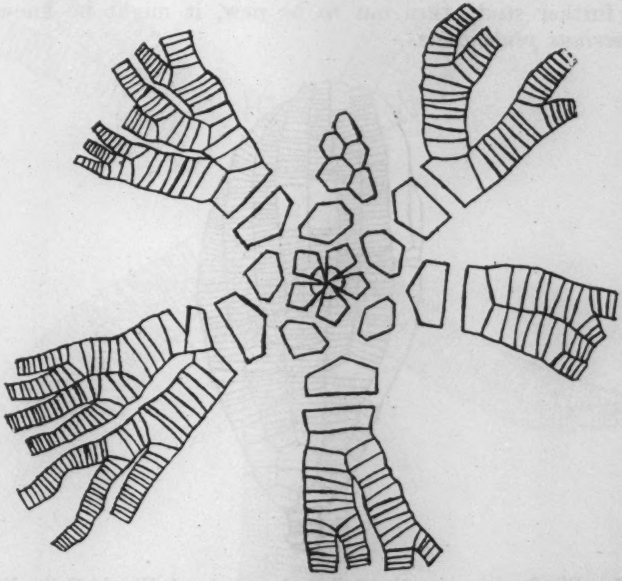

FIG. 4.—*Woodocrinus* cf. *expansus* de Kon. Diagrammatic sketch of specimen No. 2105, J. Wright Colln., Penton Linns, Liddesdale. Nat. size.

(3) The IIBr are uniformly more in number in my specimen. In No. 2105 these proportions are :—

	right ramus.	left ramus.
Right posterior ray . .	8	8
Right antero-lateral ray . .	6	8
Anterior ray	6	10
Left antero-lateral ray . .	6	8
Left posterior ray . . .	3	7

In Roberts' figure, two only of the rays are completely seen, the anterior and left or right antero-lateral, which of these latter is

not clear from the figure. The proportions here are 5 : 5 and 4 : 4, or 4 : 4 and 5 : 5. In Roberts' figure the cup looks very large in relation to the size of the arms, but without seeing the specimen it is impossible to say how far this is correct. In No. 2105 the tips of the arms are broken away, so that it is doubtful if the arms bifurcated any more than is shown in Text-figs. 2, 3, and 4 and Pl. XV. We can, however, see that the branching is also somewhat different, and the arm-plates appear to be wider.

Considering the differences here noted, it seems evident we have in No. 2105 either a very interesting variety of *Woodocrinus expansus* or perhaps a new species. Since, however, I have only Roberts' figure for comparison and not the specimen itself, I think it better meantime to refer No. 2105 to *Woodocrinus* cf. *expansus*. Should it on further study turn out to be new, it might be known as *Woodocrinus pentonensis*.

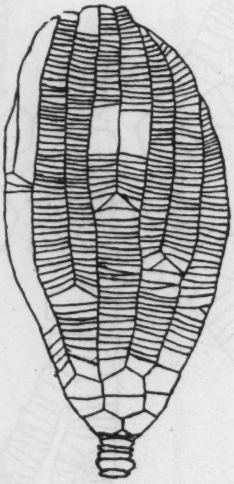

FIG. 5.—*Woodocrinus* sp., No. 3 Bed, Invertiel. J. Wright Colln. No. 429. Anterior view to show relative size of cup to arms, etc. Nat. size.

I have compared No. 2105 with all my Fife specimens of *Woodocrinus*, numbering some thirty-five individuals, and find that none quite agree with it. We have in these Fife forms some curious instances of arm structure and branching and probably most of the specimens belong to undescribed species. As an example, I give a sketch of No. 429 from No. 3 Bed, Invertiel (Text-figs. 5 and 6), the arms of which are heavy and rounded, not unlike those of *W. macrodactylus* but with different branching and cup small in relation to the arms. Other specimens have finer arm structure with more complicated branching and a larger cup.

In the paper of Peach and Horne already referred to, among

the fossils from Penton Linns are noted *Forbesiocrinus* and *Hydrieonocrinus globularis*. (*Poteriocrinus crassus* is also recorded, but I have not seen the specimen and it is possibly a portion of stem.) According to the researches of Dr. Springer, embodied in his magnificent work *The Crinoidea Flexibilia*, Washington, 1920, the genus *Forbesiocrinus* has not been recorded from Britain. *Forbesiocrinus nobilis*, founded by de Koninck and Le Hon, was erroneously identified by these authors with *Taxocrinus nobilis*

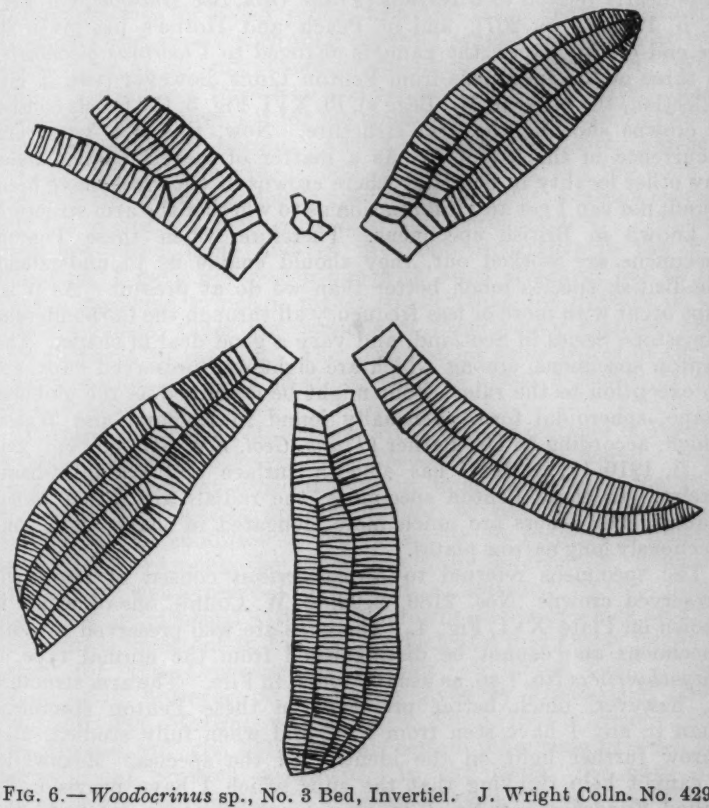

FIG. 6.—*Woodocrinus* sp., No. 3 Bed, Invertiel. J. Wright Colln. No. 429, to show arm structure. Nat. size.

Phillips. Through the kindness of Dr. G. W. Lee, I have seen the specimen recorded by Peach and Horne (Survey Office, Edinburgh, No. M4525B), and although somewhat crushed and requiring further cleaning, it seems to me to be an *Onychocrinus* and probably of the same species as the specimen found by myself, No. 2174, J. W. Colln. (Pl. XVI, Fig. 1), which comes near to *Onychocrinus pulaskiensis* Miller and Gurley (*Crinoidea Flexibilia*,

p. 437, pl. lxxiv). The survey specimen is a somewhat more mature individual than mine, and both have the surfaces of the plates ornamented with coarse tubercles and wrinkles. Meantime, until a thorough comparison can be made between the two specimens, I have recorded both in the list as *Onychocrinus* near *pulaskiensis* M. and G.

As regards *Hydrieonocrinus globularis*, Dr. Bather now looks upon the cups to which this name has usually been given as being more nearly related to *Ulocrinus* (*Trans. Geol. Soc. Glasgow*, vol. xvi, pt. ii, 1916–17, p. 207), and in Peach and Horne's list given at the end of this paper, the name is changed to *Ulocrinus globularis*. In three of the specimens from Penton Linns, however (two in my collection, the other in Mr. Begg's), Pl. XVI, Fig. 3, the fossils consist of crowns showing the arm structure. Now, this is a very rare occurrence in this country. As a matter of fact, I cannot trace any other locality in Scotland where crowns of *Ulocrinus* have been found, nor can I get any information as to whether the arm structure is known in British specimens. Therefore, when these Penton specimens are worked out, they should enable us to understand the British species much better than we do at present. As it is, cups occur with more or less frequency all through the Carboniferous Limestone Series in Scotland, and vary a good deal in shape. The Penton specimens, among which are eight well-preserved cups, are no exception to the rule. Four might be described as the globular shape, spheroidal form as usually found in England and Wales, which, according to Dr. Bather (*Trans. Geol. Soc. Glasgow*, vol. xvi, pt. ii, 1916–17, p. 214), has smooth surface and low infra-basal circlet. In these Penton specimens, the radials are rather broad plates. The others are much more elongated in shape, with conspicuously long narrow plates.

The specimens referred to *Eupachycrinus* consist of two well-preserved crowns (Nos. 2189, 2192, J. W. Colln.), one of which is shown on Plate XVI, Fig. 4. The cups are well preserved in both specimens and cannot be distinguished from the normal type of *Eupachycrinus* No. 1 sp. as usually found in Fife. The arm structure is, however, much better preserved in these Penton specimens than in any I have seen from Fife, and when fully studied, may throw further light on the identity of the species. Meanwhile, I cannot help thinking that the cups which I have provisionally called *Eupachycrinus* No. 1 sp. may eventually turn out to be the same as *Eupachycrinus calyx* MacCoy (*Ann. Mag. Nat. Hist.*, ser. II, vol. ii, p. 244, April, 1849, *Brit. Palae. Foss.*, pl. 3.D. figs. 1. 1.*a.*; *Trans. Edinb. Geol. Soc.*, vol. x, pt. 1., 1911–12, p. 73). As noted elsewhere (*Trans. Geol. Soc. Glasgow*, vol. xvi, pt. iii, 1917-18, p. 364), when a large series of cups of the *Eupachycrinus* No. 1 sp. type are examined, one notices considerable variation in the arrangement of the plates of the anal area as well as in the shape of the cup. From this, I am constrained to think it is even

possible that the species described and figured by de Koninck as *Hydrieonocrinus scoticus* (*Geologist*, No. iv, April, No. v, May, 1858), and referred to *Eupachycrinus* by Dr. Bather (*Trans. Edinb. Geol. Soc.*, vol. x, pt. i, 1911–12, p. 71) may also be found to belong to *E. calyx* (or No. 1 sp.), probably a variation of it. Possibly, therefore, the Penton specimens may eventually have to be relegated to *Eupachycrinus calyx*. Meantime, until more light is forthcoming on the subject, I place them with some doubt under that species.

Two crushed crowns occurred at Penton and probably belong to *Scytalecrinus* or allied genus, also two large crowns belonging to some *Poteriocrinid* with long tapering arms. Little can be said about those at present. Another specimen, No. 2198 J. W. Colln., closely resembles a form which is common in the "Hurlet" limestone of Fife, determined for me some years ago by Dr. Bather as *Poteriocrinus* near *plicatus* Austin (*Trans. Geol. Soc. Glasgow*, vol. xvi, pt. iii, 1917-18, p. 382, pl. xv, fig. 3). In the form of the cup, the Penton and Fife specimens resemble Austin's species, but the plates are more rugose in surface characters. Although cups are often large and of frequent occurrence in the Fife limestone, I have never seen one with arms attached, but in the Penton specimen (which is rather smaller than the average of the Fife specimens) there are portions of three heavy rounded arms still adherent to the cup. The arm ossicles show traces of coarse ornamentation. In this specimen there is about 4 inches of the stem in place.

At Harelawhill and Peterscrook, within a short distance of Penton, several specimens belonging to *Rhodocrinus* were found. They consist of somewhat crushed cups in some cases with the stem attached. The species appears similar to one which occurs in Fife but in the condition of the specimens, its identity is difficult to establish. Among the specimens from Peterscrook, however, are a few well-preserved cups and a flattened crown. These specimens are identical with several crowns and cups which occur in the Ardross limestone in Fife, all of which at a first glance might be taken for the *Cromyocrinus simplex* of Trautschold. Closer examination, however, of the figures given by Trautschold (*Bull. Soc. Imp. Nat. Moskau*, vol. xl, pt. ii, No. 3, 1867; *Nouv. Mem. Soc. Moscau*, vol. xiv, 1879), reveals certain differences between the Russian and Scottish specimens. In the latter, the cup, like *Cromyocrinus simplex* and *C. geminatus*, is smooth and rounded in outline, but, unlike these, it is distinctly saucer or shallow bowl-shaped and not constricted above. The basals are not specially large plates and are of normal proportions compared with the radials, more like *Eupachycrinus* No. 1 sp. in this respect as well as in the arrangement of the anal plates. The cup comes nearer to *Cromyocrinus geminatus* than to *C. simplex*, and the arm structure resembles the former species, the IBr or IAx in each ray being a somewhat broad plate of rather more height than the radial beneath, its upper

margin having steep sloping sides from which two uniserial arms are given off. According to the diagnosis of Wachsmuth and Springer (*Revision of the Palaeocrinoidea*, pt. iii, 1886, p. 247), the Scottish specimens would scarcely come under *Cromyocrinus*, since it is stated that the cup in that genus is globular and constricted above. Altogether, I have doubts about the determination of these specimens. It is clear, however, that they do not belong to the usual type of *Eupachycrinus* as found in Scotland but to a genus like *Cromyocrinus* or allied form with smooth plates, IBB not sunk in a shallow pit and a saucer-shaped cup. *Cromyocrinus geminatus* being the nearest described form with which I can compare them, I have meantime placed them provisionally under that species.

Conclusion.

The fauna above noted is chiefly remarkable for the predominance of one species, namely, *Woodocrinus macrodactylus*, and in this respect most closely resembles the Richmond fauna. The remaining species, comparatively few as individuals, do not form a big list and cannot be adequately dealt with at present. In fact, other than the species of *Woodocrinus*, they seem to differ somewhat from the Richmond list, if one may judge correctly from Roberts' paper (Geol. Mag., Vol. II, 1865, p. 163). At the same time, the Richmond fauna, as far as it goes, appears to have close affinities with that of the " Hurlet " limestone of Fife, with which the Penton limestone is correlated by Peach and Horne. Thus one notes among the Richmond crinoids, **Hydrieonocrinus*, *Platycrinus*, and *Mespilocrinus*. These three genera, along with *Zeacrinus*, *Eupachycrinus*, *Ulocrinus*, and *Onychocrinus* (which are not mentioned in the Richmond list) are usually closely associated with *Woodocrinus* in the Fife limestone (*Trans. Geol. Soc. Glasgow*, vol. xvi, pt. iii, 1917–18, p. 364), while at Penton, species of *Eupachycrinus*, *Ulocrinus*, and *Poteriocrinus*, indistinguishable from Fife forms, and perhaps a new species of *Onychocrinus*, have so far turned up. The last named is interesting as a new record for the south of Scotland of a member of the Flexibilia—rare fossils at most localities—the only other known occurrence being *Wachsmuthicrinus ponderosus* Springer, from the Lower Carboniferous of Jedburgh (*Crinoidea Flexibilia*, p. 333, pl. xliv), the specimen of which is in the British Museum.

As regards the species of *Woodocrinus*, it is much to be desired that full descriptions should be given. In a letter recently received from Dr. Springer, he tells me the genus *Woodocrinus* has not been recognized in American rocks, and that the reference to it of a number of species by Wachsmuth and Springer (*Revision of the Palaeocrinoidea*, pt. iii, 1886, p. 239) should be disregarded, as he has himself done for a long time. Such a characteristic British genus should, therefore, prove of some use in stratigraphical zoning. Its occurrence in its typical form at Penton certainly suggests the

linking up of the Liddesdale bed with that of Richmond in Yorkshire. At the same time, the occurrence of the genus, together with the faunal assemblage in general, also supports Peach and Horne's correlation of the Penton limestone with the "Hurlet" of Fife, in which, as at Roscobie, Invertiel, etc., *Woodocrinus* and other crinoid genera occur.

* NOTE.—*Hydrieonocrinus woodianus* de Kon. discussed by Dr. Bather in *Trans. Edin. Geol. Soc.*, vol. x, pt. i, 1911–12, p. 61, presumably comes from the Richmond horizon. Dr. Bather considers some of the Fife specimens may prove to belong to this species.

LIST OF CRINOIDS FROM LIDDESDALE.

Recorded by Peach and Horne in *Trans. Roy. Soc. Edinb.*, vol. xl, pt. iv, No. 32, 1903.

1.	*Ulocrinus globularis* de Kon. . .	Harelawhill, Penton Linns.
2.	*Forbesiocrinus* (*Onychocrinus* near *pulaskiensis* M. & G.)	,,
3.	*Poteriocrinus crassus* Miller	,,

In collections of J. Wright, J. L. Begg, etc. (see above).

1.	*Woodocrinus macrodactylus* de Kon.	Penton Linns.
2.	,, cf. *macrodactylus* de Kon.	,,
3.	,, cf. *expansus* de Kon.	,,
4.	*Ulocrinus globularis* de Kon. cups	,,
	,, ,, ,, crowns	,,
5.	*Poteriocrinus* near *plicatus* Austin	,,
6.	*Poteriocrinid* (with long tapering arms)	,,
7.	*Scytalecrinus* or allied genus.	,,
8.	*Eupachycrinus* (?) *calyx* MacCoy	,,
9.	*Onychocrinus* near *pulaskiensis* M. & G. . . .	,,
10.	*Rhodocrinus* sp.	Harelawhill, Peterscrook.
11.	Cf. *Cromyocrinus geminatus* Trautschold . .	Peterscrook.

EXPLANATION OF PLATES XIII–XVI.

PLATE XIII.

Woodocrinus macrodactylus de Kon. J. W. Colln., No. 2177. Penton Linns, Liddesdale. Slightly over one-half natural size.

PLATE XIV.

Large slab with remains of two crinoids. On the right, the flattened crown with column is referred to *Woodocrinus* cf. *macrodactylus*. The arm branching is irregular. Column measures 14 inches in length and is not complete. On the left is a more typical *W. macrodactylus* with rays spread out, ventral surface upward. The pinnules and interior of arms are well shown in the specimen. J. W. Colln., No. 2173. Penton Linns, Liddesdale. One-third natural size.

PLATE XV.

Woodocrinus cf. *expansus* de Kon. Fig. 1, posterior view. Fig. 2, anterior view. In this specimen, the column lies embedded in the shale but the crown can be removed and reversed, hence the column remains the same in both photographs. J. W. Colln., No. 2105. Penton Linns, Liddesdale. Natural size.

PLATE XVI.

FIG. 1.—*Onychocrinus* near *pulaskiensis* Miller and Gurley. J. W. Colln., No. 2144.
FIG. 2.—*Woodocrinus* sp. J. W. Colln., No. 2191.
FIG. 3.—*Ulocrinus* sp. J. W. Colln., No. 2123.
FIG. 4.—*Eupachycrinus* ? *calyx* MacCoy. J. W. Colln., No. 2189.
All Penton Linns, Liddesdale. Natural size.

REVIEWS.

THE ARCHÆOLOGY OF THE CAMBRIDGE REGION. By CYRIL FOX, Ph.D., F.S.A. pp. xxv+360, with 37 plates, 1 text-figure, 9 text-maps, and 5 coloured maps in pocket. Cambridge: University Press, 1923. Price 31*s.* 6*d.* net.

ALTHOUGH the actual subject matter of this book is almost entirely outside the scope of geology in the strict sense, nevertheless many geologists are so deeply interested in the sciences bordering on their own that we need feel no hesitation in mentioning it here. The work, as a matter of fact, begins with a short chapter devoted to the Neolithic Age, giving an account of local finds and their bearing on subsequent phases of culture, but the greater part is occupied by a detailed consideration of the remains of periods from the Bronze Age up to the Norman Conquest. Nevertheless, all through the book the writer shows that he is fully alive to the significance of the geological structure of the country and the distribution of the superficial deposits as controlling factors in human settlement and the development of the historical aspect. It so happens that the Cambridge region affords a particularly clear example of this influence, in the strong contrast that exists between the Fenland, the open Chalk country of down type and the heavy clay areas, including the boulder clays, the last-mentioned group having originally been almost exclusively forest land, and therefore late in development. The influence of the Chalk country on the distribution of population, the growth of agriculture and industry, and the means of transport, is well known to everybody, and doubtless in early days the complicated and elaborate river system of the Fenland was also an important factor.

We should like to congratulate Dr. Fox on having brought out these important points so clearly in his scholarly book, which is beautifully produced, with numerous admirable plates. It cannot fail to appeal to a wide circle of readers beyond the bounds of archæologists in the strict sense, since it gives an intelligible and graphic picture of life in East Anglia during a period which most of us are too much inclined to regard in its earlier stages, at any rate, as one of unmitigated savagery, varied by foreign invasions. It is now beginning to be recognized that the "Ancient Britons" of at any rate southern and south-eastern England were not in immediately pre-Roman times merely a horde of naked barbarians painted blue, but a comparatively civilized race possessing a culture much like that of Gaul or even of the parts of Italy remote from Rome. Dr. Fox's book should do a good deal to dispel the cloud that hangs over the earlier chapters of most "Histories of England" from the largest to the smallest in scale, and to give us a truer picture of the lives of our predecessors in this land.

MEMOIRS OF THE GEOLOGICAL SURVEY OF SCOTLAND: The Geology of the Country round Banff, Huntly, and Turriff. Explanation of sheets 86 + 96. 1923. pp. i–viii and 1–240, text-figs. 1–11. Price 6*s.* 6*d.* net.

THE district here described affords opportunity for the study of several geological problems, and geologists are not likely to be unanimous in their acceptance of the solutions offered by Mr. Read, but he is certainly to be congratulated on the lucid way in which he has presented the main points at issue and the clearness with which they are illustrated in the maps incorporated as text-figures. Interest will centre chiefly round the new facts recorded concerning the Highland Schists, and the evidence for the contamination of the Younger Igneous Rocks by the incorporation of sedimentary material.

The Banffshire coast affords a magnificent natural section of the Highland Schists, which are here considered to fall into two groups, a W. or Keith division, and an E. or Banff division; there would appear to be considerable support for the view that certain members of the Keith division may be correlated with some of the Dalradian Series of Perthshire, though it may be doubted whether the Ben Lawers Schists would ever give rise to rocks of the type of the Cowhythe Gneiss. About the members of the Banff division divergent views are held: they may be confined to N.E. Scotland and be absent in Perthshire as Read suggests, or they may represent the rest of the Perthshire succession as Horne has suggested, but the idea that they correspond with rocks in Bailey's Loch Awe syncline seems to have very little to support it. The actual relationship of these two divisions as seen on the Banff coast is extremely interesting, and the facts have been differently interpreted. Read's interpretation depends largely upon a supposed difference in metamorphic grade between the two divisions, but this does not seem to be borne out by his petrographic notes. Schists containing biotite, garnet, and staurolite (p. 59) have surely advanced far beyond the grade of phyllites. So that his argument that the rocks of the Banff division must structurally overlie those of the Keith division loses its force, and this carries with it to some extent his interpretation of the line of discordance between the two divisions as a thrust. This Boyne line is considered by Horne to be due to normal faulting and this carries more conviction with it than the thrust theory, though if it were an early plane of movement the hade as now seen need not represent the original inclination, and the absence of mylonitisation might be accounted for by its deep-seated nature.

Intrusions belonging to two distinct periods of igneous activity are found within these Schists; the earlier termed the Older Igneous Rocks, have shared largely in the movements affecting the Schists, and must therefore have been intruded either just before or during these movements, the later, the Younger Igneous Rocks, are later than the movements, but were intruded before the deposition of the

Middle O.R.S. in which fragments are found as pebbles. The Older Igneous Rocks form a complex of sill-like masses comprising ultra basic and acid members, the field relations suggesting differentiation prior to intrusion; basic types predominate, the least altered rock is a gabbro, and according to the degree of replacement of the pyroxene by hornblende and the recrystallization of the felspar gives rise successively to epidiorites and amphibolites in the less schistose types, and to gabbro-schists and hornblende-schists where schistose structures are well developed. It would be interesting to know how far this classification can be maintained in the field!

Differences of opinion will almost certainly be held in regard to some of the details connected with the Younger Intrusives. A norite is the predominating type in the Huntly complex, and this norite is believed to have been contaminated at its margin by the incorporation of aluminous material from the "phyllites", and to have consolidated as two different rocks, a non-garnetiferous rock containing 50 per cent cordierite (cordierite-norite) and a garnetiferous biotite-plagioclase rock in which the place of the cordierite is taken by andesine. This rock is regarded as the extreme type of contamination. Analyses are given showing the gradual increase in the alumina content, and many people will be disposed to admit this type of contamination, but it is probable that they will hesitate to accept the same interpretation for the diorites and monzonites of the Central Intrusion.

The remaining chapters of the Memoir are devoted to the Middle O.R.S., Glacial geology and Economics. The facts now put forward show clearly that there were three stages in the glacial history of this area; in the first, the ice moved S.E. over the Moray Firth, in the second, this ice withdrew, and the clays, sands and gravels constituting the Coastal Deposits were laid down, perhaps in water held up between the N. creeping ice and the retreating Scandinavian ice, and in the third the ice from the S. crept N.

G. L. E.

NON-FERROUS METALS AND OTHER MINERALS. The Resources of the Empire Series. Edited by N. M. PENZER, with a Foreword by the PRINCE OF WALES and Introductions by SIR ERIC GEDDES and SIR RICHARD REDMAYNE. pp. 264. London: Ernest Benn, Ltd. 1924. Price 21*s.* net.

THE series of which this book forms vol. viii, part ii, is of course obviously and rightly inspired by the Wembley Exhibition, and is published under the auspices of the Federation of British Industries. It contains in a handy form a brief account of the properties, mode of occurrence, and production of a list of 33 minerals, the term "mineral" being interpreted in a wide but common-sense manner to include such things as Portland cement, china clay, and fuller's earth. The treatment is naturally largely statistical, and a strong point of the work lies in the large number of references

to the literature scattered through the text. In addition there is a very useful bibliography of 34 pages, which seems to be fairly complete, although it does not claim to be exhaustive. The book should be very useful to those in search of information as to the occurrence of mineral products anywhere within the Empire.

CORRESPONDENCE.

THE AGE OF THE HIRNANT BEDS.

SIR,—I feel that some explanation is needed of the long interval which has elapsed without my replying to Dr. Elles' letter on the above subject in the GEOLOGICAL MAGAZINE (December, 1923). On my return from Bwlch y groes last summer, I had marked on my reprint of Dr. Elles' paper, which appeared in the GEOLOGICAL MAGAZINE for September, 1923, the corrections which were required to bring the sketch-map of Bwlch y groes on p. 412 of that issue into accordance with the facts as revealed by the examination of the ground by Professor Pugh and myself. This copy was mislaid until recently. In the meantime, however, Professor Pugh's paper on the Ordovician–Silurian succession in the adjoining area to the south has appeared in the *Quarterly Journal of the Geological Society* (December, 1923), and reference to this paper will make clear my reasons for my belief in the Ordovician age of the Hirnant shales. In the first place I must disclaim any "eagerness" to prove their Ordovician age, but I have felt that Dr. Elles has been working on a false basis ever since she attributed the Conway Castle Grit with its Ordovician fauna to the Silurian. It was the statement that the Bwlch y groes locality yielded definite evidence of the Silurian age of the Hirnant Beds which induced me to visit that locality and subsequently to enter into this controversy. Dr. Elles' map shows on the west side of Bwlch y groes the Moelfryn sandstones dipping eastward under the Foel y Ddinas mudstones (*Phacops mucronatus* beds) and these in turn under the Lower Valentian which yielded graptolites of the *M. atavus*-zone. Actually the sandstones dip in the opposite direction and are faulted against Valentian rocks on the east. On this side of the pass, therefore, where Dr. Elles obtained a *Phacops* referred to *P. mucronatus* there is no succession from the true *P. mucronatus* beds or Foel Ddinas mudstones to the Valentian. Near the centre of the pass there is, however, a continuous succession from the Moelfryn sandstones through these mudstones to a higher group of dark-blue mudstones. The latter are included by Dr. Elles in the Valentian, but they lie below the lowest beds of the Valentian rocks which are present in full development in the crags to the south.

These dark-blue mudstones are the equivalents of Professor Pugh's Garnedd Wen beds at Corris (*Q.J.G.S.*, vol. lxxix, table facing p. 515), which yielded *P. mucronatus* at their base (ibid., p. 525). They are

also the equivalents of the Drosgol grits and Brynglas mudstones which overlie the *Dicellograptus anceps* beds in the Plynlimon district. As Professor Pugh has shown, they diminish rapidly in thickness and become finer-grained when traced northwards through Central Wales. It is these beds which appear to pass northwards between Bwlch y groes and Hirnant into the Hirnant shales. The change is even beginning south of Bwlch y groes, where occasional fossils appear in them. The Bwlch y groes locality, therefore, not only affords no evidence that the Hirnant shales are Valentian, but on the contrary proves that they underlie the whole of the Valentian of Central Wales.

Dr. Elles in her recent communication states that she found *P. mucronatus* at about 5 inches vertically below the *Dimorphograptus* beds. Since about 200–300 yards to the east the *Dimorphograptus* beds are underlain by about 100–150 feet of still lower Valentian beds the specimen of *Phacops* must have been obtained from these Valentian beds. The species has been previously recorded from the Valentian, as Dr. Elles states, but it is rare in those rocks, and Dr. Elles is to be congratulated upon adding a further record. From her remarks about *Ph. eucentra* and *P. mucronatus* s.s. it seems that Dr. Elles envisages this as a possible explanation.

I fail to see how my statement that the position of the *P. mucronatus* beds in the Plynlimon district is 2,400 feet below the base of the Silurian is " most misleading ". It is a statement of fact, and I do not see that the additional statement which Dr. Elles demands that it also overlies the *Dicellograptus anceps* zone adds any material information unless Dr. Elles is under the impression (which I find difficult to believe) that the top *zone* of the Ordovician (zone of *D. anceps*) is also the top of the Ordovician. That zone is separated from the top of the Ordovician by strata, mostly barren, ranging in thickness from 2,400 feet in Central Wales to 10 feet (" Barren band ") in the Southern Uplands of Scotland. It is in these barren beds that locally, as at Hirnant, Conway, and Ashgill, the Hirnant fauna is developed.

One word more ; as the author of the species *Monograptus atavus* I may claim to hold certain opinions regarding its characteristics, but I find that Dr. Elles appears to confuse undoubted specimens of that species with *M. cyphus* with which it has little in common. This point is, however, of small importance, since in the Lake District there are reasons for supposing that a considerable break occurs between the " *Dimorphograptus* beds " and the Ashgill shales. The missing strata are, however, fully developed at Bwlch y groes and elsewhere throughout Central Wales.

O. T. Jones.

The University, Manchester.
25*th March*, 1924.

RIFT-VALLEYS AND TROUGH-VALLEYS.

SIR,—Professor J. W. Gregory, the originator of the term, defines a "rift-valley" as a depression due to the sinking of a band of country between parallel faults; or, in other words, as the surface expression of a trough-fault or fault-trough. Judging by the discussion that took place on Professor S. J. Shand's paper, "A Rift-Valley in Western Persia" (*Q.J.G.S.*, vol. lxxv, 1919, p. 245), this definition finds fairly general acceptance.

In his admirable article on Structural Geology in the New Volumes of the *Encyclopædia Britannica*, Professor Grenville Cole suggests that "trough-valley" would be a more suitable term for such structures.

It has recently been my privilege to translate and present to the Geological Society of South Africa a valuable paper [1] by Dr. Werner Beetz, in which that author describes a great depression in the Namib (South-West Africa) due to the foundering of a segment of the earth's crust 185 kilometres in length and some 40 kilometres in width; the sunken area being bordered not by faults, but by great monoclinal flexures, admirably exposed owing to the almost complete absence of soil and vegetation.

Dr. Beetz described this remarkable feature as a Graben, and suggested that "rift-valley" would be a suitable translation. As, however, rifting or faulting has here played a negligible rôle that term would have been misleading. After consultation with Dr. A. W. Rogers it was accordingly decided to call it a *tectonic trough* or simply a *trough*, and its expression at the surface a *trough-valley*. This was before I was aware of Professor Grenville Cole's suggestion.

As to the latter, it appears desirable, now that the existence of structures such as that described above has been established, to have a specific name for them.

Would it not be better, therefore, to retain the term "rift-valley", which has won such wide popularity, for depressions of this nature, where faulting can be proved to have occurred, reserving "trough-valley" for those bounded by monoclinal folds?

PERCY A. WAGNER.

GEOLOGICAL SURVEY OFFICE, PRETORIA.
14th April, 1924.

OBITUARY.

Grenville A. J. Cole, F.R.S.

Professor Grenville A. J. Cole, one of the most brilliant and versatile of the school of geologists which sprang up towards the end of the last century under the inspiring influence of Professor Judd,

[1] "On a Trough Valley in the Namib," *Trans. Geol. Soc. South Africa*, 1924, p. 1.

passed away at his residence at Carrickmines, Co. Dublin, on 20th April. He had long been a prominent figure in scientific circles in Dublin, and his place will be hard to fill. He held the Professorship of Geology in the Royal College of Science for Ireland from 1890 until his death, and was Dean of the College for two years. In 1905 he became Director of the Geological Survey of Ireland, then for the first time brought under the control of an Irish Department.

Cole was born in London in 1859 and educated at the City of London School and at the Royal School of Mines. A year after his appointment to the chair in Dublin he published his *Aids in Practical Geology*, which had an immediate and striking success, running to seven editions. Few works have been so popular with all classes of geologists. Gifted with a fluent pen and a brilliant sense of literary values, he produced from this on a series of books which showed, by their ready sale, their attractiveness to the general reader and their value as popular introductions to the science of geology.

Among his more serious contributions to science are to be reckoned papers on the metamorphic rocks of Tyrone and Donegal in which he applied and developed the theory of lit-par-lit injection of the French Schools. His studies of the tachylytic selvages of basic igneous rocks, begun in association with Judd, and extended later to other varieties of glassy rocks and their devitrification products, are well known. His description of the riebeckite-rock of Mynydd Mawr was an important contribution to both petrological and glacial science in that he clearly discriminated between that rock and the riebeckite-eurite so widely distributed as erratics along the shores of the Irish Sea, and now known to be derived from Ailsa Craig in the Firth of Clyde.

It is a relief in these days of narrow specialization to review the life-work of a man of such refreshingly wide and varied interests as Cole possessed. In addition to his petrological work he effectively dealt in turn with such varied subjects as glacial geology, mineralogy, and palaeontology. His contributions to the latter include papers on *Hemitrypa hibernica*; the Fenestellidae of the Carboniferous, *Oldhamia*, and other organic remains from the enigmatical Bray Series; *Belinurus kiltorkensis*, and an Irish Cretaceous Cirripede. In association with O. H. Little he made some interesting determinations of the mineral conditions of the calcium carbonate in fossil shells, and pointed out that whereas the more recent fossils are mainly preserved as aragonite those from the older formations are invariably calcite.

We have recently re-read some of Cole's scientific papers and addresses with the object of evaluating his contribution to the advancement of science. We are struck anew by one of his outstanding characteristics, the generous acknowledgment of the work of others. He had an amazing knowledge of the literature

of his subject, and his meticulous care that no previous contribution should escape notice, was sometimes carried to such an extent as even to obscure his own line of thought. This quality of appreciation he carried also into his daily relations with others, and it was always possible for those who worked under him to gain his sympathetic co-operation in any scheme which promised results of scientific value.

Cole travelled widely, and acquired an extensive knowledge of European geology. His reputation spread far beyond the country of his adoption, and was recognized in various ways. In 1909 he was awarded the Murchison Medal by the Geological Society of London in recognition of his petrological studies on the glassy igneous rocks and his work on the metamorphic rocks of northern Ireland. He was President of the Geological Section of the British Association at Manchester in 1915; and in his opening address he took an original line in pointing out that mountain-building processes were subject to sudden and catastrophic culmination at certain periods of the world's history. Many of his conclusions and suggestions foreshadow the most modern developments of geological thought. In 1917 he was elected a Fellow of the Royal Society.

On the rise of Geography to the status of an independent science he took a keen interest in its development, and was President of the Geographical Association in 1919 and President of the Irish Geographical Association from its establishment in 1919 until 1922. His lectures and addresses in this capacity will be long remembered by those who have heard or read them as stimulating in the extreme and coloured by a delicate play of the imagination such as few scientific men can bring to the popularization of their subject. One of them entitled "The Clearing" cannot fail to live as a gem of literary exposition.

An intimate association extending over many years has given the present writers the opportunity of realizing and appreciating some very lovable features of a character whose outer brilliance and polish served but to cloak the man within. Most noteworthy of all was perhaps his intellectual courage—his refusal to gloss over the unpleasant facts of life by the use of any sophistry. He faced the world undaunted and interpreted it in the light of reason. Side by side with this scientific attitude, however, he cultivated and cherished a poetic faculty of no mean order, which found expression only seldom, but always with remarkable effect. Some of his poems show a rare appreciation of the beauty of nature and a delicacy of touch which one finds but rarely nowadays among the votaries of science. He owed much of this delightful faculty to his early training, but even more perhaps to his wife, whose mental vitality and classical culture gave them a bond of interest that became a very potent factor in influencing his development.

One does not know whether to admire most in Cole his subtlety